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CONSTRUCTION AND USE OF FARM WEIRS

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Rev.ed.
follows

FARMERS' BULLETIN 813

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CONSTRUCTION AND USE OF FARM WEIRS.

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NEED OF FARM WEIRS.

In the arid west vast sums of money have been expended in the construction of ditch and canal systems to carry water to the lands where the rainfall is either insufficient or too uncertain for profitable agriculture, and the farmers have spent a still greater amount for preparing the land for irrigation and for purchasing "water rights," which entitle them to a certain amount of water. The value of the water has increased with the development of the country and now there is a general demand that the water be measured from the ditch to the irrigator as well as from the stream to the main canal. This is an important step toward better business methods in the management of canal systems and farms, and calls for accurate and reliable information concerning devices suited to the measurement of comparatively small streams of flowing water.

DEFINITIONS.

The "weir" is one of the most commonly used devices for this purpose. A bulkhead or wall built across a ditch or stream, with an opening cut in the top of the wall through which the water is allowed to pass, is called a "weir" and the opening is called the "weir notch." The bottom portion of the ditch immediately upstream from the bulkhead is the "weir box" or "weir pond." The height of the water surface in the weir pond above the weir crest is the "head." When the water flows over the crest into the air before it strikes the surface of the water in the ditch downstream from the bulkhead, it is said to have "free fall," and when this overpouring stream of water touches only the sharp upstream edge of the crest, the weir is

NOTE.—The work on which this bulletin is based was done in the hydraulic laboratory at Fort Collins, Colo., under a cooperative agreement between the Office of Experiment Stations, United States Department of Agriculture, and the Colorado Agricultural Experiment Station.

For a technical report on the experimental data see Journal of Agricultural Research, Vol. V, No. 23, March 6, 1916.

The purpose of this bulletin is to give practical directions for the construction and use of the smaller sizes of weirs, such as are suited to the measurement of water on irrigated farms.

said to be "sharp crested." The weir notch must have a definite shape and size. The horizontal distance from the end of the weir crest to the side of the weir box is called "end contraction," and the vertical distance from the crest to the floor of the weir box is called "bottom contraction." When these contraction distances are great enough to cause a pondlike condition, which permits the water to approach the weir notch without any appreciable velocity, the weir is said to have "complete contractions."

The weirs described in this bulletin are the rectangular, Cipolletti, and 90° triangular-notch types, with free fall, sharp crests, and complete contractions. The discharge formulas for these weirs are not confined to the limits imposed upon old formulas. They are correct for high as well as low heads, at least within the range given in the tables.[1] However, in order to lessen the cost for materials for constructing the weirs, the dimensions of the weir boxes, as given in Table 1, are less than required for complete constructions, and therefore the discharges over these weirs will be greater than represented by the formula or discharge tables. The excess reaches a maximum of only about 1 per cent for the higher heads, and consequently can be ignored for practical conditions.

To determine the quantity of water flowing at any time, read the gauge, which gives the "head" or depth of water flowing over the weir notch, and turn to the discharge table in this bulletin for the type of weir used. If the head is measured in feet and decimals, find it in the first column, or if measured in feet and inches, find it in the second column, and following along this line to the right, find the number in the column for the length of weir crest used. This number will be the flow in cubic feet per second, which may be changed into miner's inches—or statute inches—by multiplying by the number of miner's inches equal to a cubic foot per second, as given in the table of hydraulic equivalents on the last page of this bulletin.

ADVANTAGES AND DISADVANTAGES OF WEIRS WITH COMPLETE CONTRACTIONS.

The principal advantages and disadvantages of the types of weirs described herein may be stated as follows:

Advantages.—They are (1) accurate; (2) they are simple and may be constructed by the farmer; (3) they permit moss and floating trash to pass through the ditch without great danger of interfering with the measurement of the water; and (4) they are durable and require no adjustment for proper operation, for there are no working parts.

[1] A full discussion of the experiments upon which these formulas are based is contained in Journal of Agricultural Research, vol. 5, No. 23, Mar. 6, 1916.

Disadvantages.—(1) They require a considerable pondage above the weir; (2) they can not be used where there is only a slight grade to the ditch; (3) they are not adapted to ditches that carry much sand and silt; and (4) practically all undesirable conditions, such as accumulation of sand and silt above the weir, water approaching the weir with velocity, or injury to the weir crest, tend to give a greater flow of water than that indicated in the tables.

WEIR BOX AND WEIR POND.

When properly constructed either of the three types of weirs described herein is reliable and accurate for the measurement of flowing water. They may be placed in any ditch or canal having sufficient fall, but it is necessary that the ditch be made wider and deeper for some distance upstream from the weir notch. This enlargement is for the purpose of making practically a still-water condition before water flows over the weir. The weir box or weir pond, which is immediately upstream from the weir notch, has a uniform length, width, and depth as given in Table 1, and commencing at approximately 50 feet upstream from the weir the ditch must be enlarged gradually from the regular size of the ditch to the full size of the weir box. The length of this tapering enlargement, stated as 50 feet, really needs to be greater or less as the flow in the ditch is large or small as compared to the size of the weir notch, and it will depend also upon the size of the ditch and the velocity of the water in the ditch.

Where the available grade in the ditch is not great enough to give the required depth of pond by raising the banks for a distance of 50 to 100 feet back from the weir, the bottom may be lowered and the banks raised only enough to give a free fall below the weir notch. However, the weir pond, whether a box or an enlargement of the ditch, must not be allowed to fill with silt and sediment or other débris. The water must approach the weir in straight lines without swirling or eddy currents.

A weir box may be built as shown in figure 1, or a bulkhead may be placed in an enlargement in the ditch as shown in figure 2. This latter arrangement will permit cleaning of the pond with teams and scrapers, and is easy and inexpensive to construct, but because of the sloping banks, the water surface must be wider than where a box is built with vertical sides. The bottom of the ditch for a short distance downstream from the weir should be lined with rock to prevent scouring due to the water falling over the weir notch. Where a complete weir box is built of timber or concrete it looks well, occupies the least land area and has greater permanency, but it is more costly and more difficult to clean. A floor or apron, as given in column K in Table 1, constructed of the same material as the weir box, over-

comes the necessity for lining the ditch with rock below the weir. Precautions should be taken to prevent water from washing under the bottom or around the sides of the box. For most soils, if the earth is puddled with water as it is filled around the box, it will be safe; but where it is sandy or likely to wash, a board 12 inches wide should be placed on edge under the bottom and at the sides near the upper end of the box, to serve as a cut-off wall. The height of the weir crest above the bottom of the ditch downstream from the weir notch will depend upon the size and grade of the ditch, but this height must be such that when the greatest quantity of water is flowing over the weir the water level in the ditch downstream will be below the crest. This is to permit the free passage of air between the bulkhead and the sheet of over-pouring water, which is the required condition for free flow.

Table 1 gives the sizes of weirs best adapted to measuring flows of water varying from one-half to 22 cubic feet per second, and the proper dimensions for each size of rectangular, Cipolletti, and 90° triangular notch weirs.

TABLE 1.—*Weir-box dimensions for rectangular, Cipolletti, and 90° triangular-notch weirs.*

[All dimensions in feet. The letters at the heads of the columns in this table refer to figure 1.]

RECTANGULAR AND CIPOLLETTI WEIRS.

Flow (second-feet).	H. Maximum head.	L. Length of weir crest.	A. Length of box above weir notch.	K. Length of box below weir notch.	B. Total width of box.	E.[1] Total depth of box.	C. End of crest to side.	D. Crest to bottom.	F.[2] Hook-gage distance.	G.[3] Hook-gage distance.
½ to 3	1.0	1	6	2	5½	3½	2½	2	4	2
2 to 5	1.1	1½	7	3	7	4	2½	2½	4½	2
4 to 8	1.2	2	8	4	8½	4½	3½	2½	5	2½
6 to 14	1.3	3	9	5	12	5	4½	3½	5½	3
10 to 22	1.5	4	10	6	14	5½	5	3½	6	3
90° TRIANGULAR NOTCH WEIR.										
½ to 2½	1.00	.....	6	2	5	3	2½	1½	4	2
2 to 4½	1.25	.....	6½	8½	6½	3½	3½	1½	5	2½

[1] This distance allows for about ½ foot freeboard above highest water level in weir box.
[2] Equals distance from crest upstream to gauge.
[3] Equals distance from end of crest over to gauge.

As previously stated, using the weir boxes specified in Table 1 will give results within 1 per cent of correct. If smaller boxes are used the actual discharges will be larger than those given in the tables.

Tables 2 and 3 show the percentage increase in discharge caused by weir boxes smaller than required for complete contractions, for rectangular and Cipolletti weirs having crest lengths from 1 to 4 feet, and with heads of six-tenths and 1 foot.

If the smaller boxes are used, discharges should be read from the tables and increased by the percentages given in Tables 2 and 3.

TABLE 2.—*Velocity of approach and percentage of error caused by different end and bottom contractions for rectangular weirs.*

B. Distance of bottom below crest.	A. Distance of sides from end of crest.	Length 1 foot.				Length 1.5 feet.				Length 2 feet.				Length 3 feet.				Length 4 feet.			
		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.	
		Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.
Feet.	*Feet.*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
3.0	2.5	.....	.....	0.132	0.77	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.0	2.0	.....	.....	.157	.81	.....	.....	0.213	0.82	.....	.....	0.269	0.84	.....	.....	0.342	0.83	.....	.....	0.402	0.87
3.0	1.5	.....	.....	.196	.099	.....	.....	.260	1.08	.....	.....	.317	1.14	.....	.....	.399	1.22	.....	.....	.460	1.29
3.0	1.0	.....	.....	.260	1.40	.....	.....	.337	1.63	.....	.....	.398	1.81	.....	.....	.484	2.06	.....	.....	.543	2.22
3.0	.5	.....	.....	.40	2.94	.....	.....	.477	3.22	.....	.....	.540	3.44	.....	.....	.616	3.72	.....	.....	.661	3.88
2.5	2.5	.....	.....	.150	.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.5	2.0	.....	.....	.178	.82	.....	.....	.242	.88	.....	.....	.302	.94	.....	.....	.391	1.04	.....	.....	.460	1.11
2.5	1.5	.....	.....	.224	1.05	.....	.....	.297	1.21	.....	.....	.362	1.34	.....	.....	.461	1.57	.....	.....	.528	1.69
2.5	1.0	.....	.....	.299	1.58	.....	.....	.385	1.89	.....	.....	.457	2.14	.....	.....	.553	2.50	.....	.....	.623	2.76
2.5	.5	.....	.....	.462	3.42	.....	.....	.549	3.73	.....	.....	.625	3.99	.....	.....	.704	4.25	.....	.....	.760	4.48
2.0	2.5	0.94	0.17	.175	.73	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.0	2.0	.115	.26	.209	.84	.....	.....	.284	.97	.....	.....	.352	1.11	.....	.....	.458	1.30	.....	.....	.539	1.42
2.0	1.5	.148	.39	.261	1.13	.....	.....	.348	1.42	.....	.....	.424	1.67	.....	.....	.538	2.01	.....	.....	.620	2.28
2.0	1.0	.188	.66	.353	1.83	.....	.....	.450	2.28	.....	.....	.535	2.63	.....	.....	.648	3.14	.....	.....	.733	3.52
2.0	.5	.288	2.05	.538	4.01	.....	.....	.646	4.46	.....	.....	.728	4.80	.....	.....	.829	5.17	.....	.....	.895	5.47
1.5	2.5	.119	.17	.208	.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.5	2.0	.141	.30	.252	.94	1.91	0.53	.341	1.18	0.239	0.74	.424	1.41	0.308	1.07	.539	1.71	0.365	1.33	.638	1.98
1.5	1.5	.175	.40	.314	1.31	.234	.73	.418	1.74	.286	1.01	.512	2.12	.363	1.44	.648	2.65	.416	1.74	.750	3.07
1.5	1.0	.234	.76	.424	2.24	.304	1.24	.544	2.87	.361	1.62	.646	3.40	.435	2.12	.790	4.14	.489	2.49	.889	4.68
1.5	.5	.355	2.26	.648	4.80	.....	.....	.784	5.53	.....	.....	.885	6.09	.552	3.41	1.013	6.77	.....	.....	1.091	7.20
1.0	2.5	.154	.19	.260	.82	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.0	2.0	.209	.36	.314	1.12	.....	.....	.427	1.57	.....	.....	.532	2.00	.....	.....	.694	2.69	.....	.....	.810	3.15
1.0	1.5	.229	.50	.385	1.59	.311	1.09	.528	2.37	.377	1.55	.645	2.99	.478	2.25	.820	3.91	.552	2.79	.952	4.60
1.0	1.0	.308	1.01	.525	2.83	.400	1.77	.688	3.86	.476	2.39	.825	4.73	.577	3.22	.999	5.87	.650	3.83	1.135	6.77
1.0	.5	.469	2.84	.822	6.00	.573	3.74	.994	7.29	.646	4.38	1.129	8.29	.735	5.15	1.298	9.55	.794	5.64	1.405	10.27
.5	2.5	.221	.25	.350	1.11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.5	2.0	.265	.50	.417	1.45	.368	1.30	.575	2.40	.460	2.05	.720	3.27	.624	3.34	.943	4.62	.711	4.05	1.120	5.65
.5	1.5	.337	.94	.530	2.20	.453	1.94	.710	3.53	.555	2.84	.875	4.73	.705	4.17	1.119	6.50	.818	5.15	1.308	7.88
.5	1.0	.450	1.84	.716	3.83	.588	3.22	.930	5.65	.704	4.35	1.118	7.23	.862	5.92	1.380	9.40	.975	7.01	1.576	11.2
.5	.5	.695	4.63	1.120	8.25	.852	6.43	1.37	11.0	.970	7.79	1.58	13.3	1.112	9.40	1.83	16.01	1.238	10.50	2.01	18.0

TABLE 3.—*Velocity of approach and percentage of error caused by different end and bottom contractions for Cipolletti weirs.*

B. Distance of bottom below crest.	A. Distance of sides from end of crest.	Length 1 foot.				Length 1.5 feet.				Length 2 feet.				Length 3 feet.				Length 4 feet.			
		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.	
		Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.
Feet.	*Feet.*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
2.0	2.0	.....	.....	0.250	1.19	.....	.....	0.322	1.22	.....	.....	0.386	1.24	.....	.....	0.488	1.28	.....	.....	0.561	1.30
2.0	1.5	.....	.....	.314	1.52	.....	.....	.397	1.70	.....	.....	.467	1.84	.....	.....	.575	2.08	.....	.....	.648	2.22
2.0	1.0	.....	.....	.422	2.40	.....	.....	.514	2.80	.....	.....	.590	3.15	.....	.....	.698	3.62	.....	.....	.769	3.92
2.0	.5	.....	.....	.655	6.16	.....	.....	.746	6.41	.....	.....	.813	6.61	.....	.....	.896	6.88	.....	.....	.951	7.01
1.5	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.5	2.0	0.158	0.84	.300	1.34	0.207	1.02	.388	1.49	0.251	1.21	.465	1.61	0.321	1.45	.590	1.82	0.373	1.61	.680	1.98
1.5	1.5	.196	1.11	.378	1.78	.255	1.38	.477	2.10	.304	1.60	.562	2.40	.377	1.95	.693	2.85	.429	2.19	.785	3.17
1.5	1.0	.260	1.70	.508	2.89	.329	2.08	.622	3.53	.381	2.36	.714	4.06	.454	2.77	.844	4.79	.504	3.02	.937	5.31
1.5	.5	.400	3.32	.795	7.29	.469	3.83	.906	7.79	.518	4.20	.989	8.18	.580	4.66	1.094	8.64	.617	4.93	1.163	8.85
1.0	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.0	2.0	.205	.09	.374	1.60	.274	1.25	.489	2.06	.331	1.55	.586	2.44	.425	2.05	.758	3.13	.492	2.39	.864	3.55
1.0	1.5	.257	1.20	.471	2.20	.335	1.71	.601	2.92	.400	1.55	.710	3.55	.500	2.82	.888	4.53	.569	3.30	1.003	5.19
1.0	1.0	.344	1.84	.643	3.76	.434	2.60	.787	4.83	.501	3.17	.908	5.73	.607	4.06	1.083	7.07	.671	4.60	1.200	7.92
1.0	.5	.529	4.00	1.010	9.20	.622	4.92	1.159	10.28	.690	5.61	1.271	11.08	.770	6.41	1.410	12.09	.826	6.98	1.503	12.72
.5	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.5	2.0	.300	1.11	.508	2.30	.399	1.81	.660	3.64	.487	2.42	.799	4.87	.625	3.40	1.013	6.73	.725	4.09	1.202	8.39
.5	1.5	.377	1.51	.640	3.30	.492	2.55	.818	4.80	.589	3.44	.969	6.09	.737	4.79	1.210	8.08	.847	5.80	1.391	9.56
.5	1.0	.505	2.39	.864	5.40	.636	3.93	1.077	7.58	.750	5.30	1.258	9.43	.908	7.18	1.505	11.95	1.013	8.39	1.688	1.38
.5	.5	.782	6.03	1.390	11.89	.932	8.02	1.605	14.63	1.037	9.43	1.782	16.85	1.173	11.28	2.015	19.80	1.263	12.48	.....	.....

WEIR CRESTS AND SIDES.

Weir crests and sides should be true, straight, and rigid. The crest must be level, the sides must be set to the proper angle with the crest, and carefully spaced to give the correct length of crest, as indicated by "L" in figure 1 and Table 1. The 90° triangular notch has no length of crest because the sides meet at a point.

It is not necessary that the sides and crest be sharpened to a knife edge, but the edge of the crest on the upstream side must be sharp in the sense that it is not rounded. If a depth of water not less than 3 inches is to be run over the weir, the crest thickness on the edge may be as great as one-fourth inch without the water adhering to the crest, provided the inner edge is sharp. However, if the crest is beveled, this bevel must be placed on the downstream side, for the upstream face of the crest and of the bulkhead which holds the crest must be even and in a vertical position. The downstream face of the opening in the bulkhead must be beveled outward and downward about 45 degrees to insure free passage of air under the sheet of water as it flows over the weir.

Instead of cutting the notch in the bulkhead to just the size desired and leaving this rather rough edge to serve as the crest and sides of the weir notch, it is better to make the opening in the bulkhead at least 1 inch deeper and 2 inches wider than the desired size of weir opening. This will permit attachment of crest and side strips to the bulkhead so as to project about an inch all around, making more perfect edges, and the overpouring sheet of water will not touch the bulkhead.

Wood may be used for the crest and sides, but as it is apt to warp, wear, and become splintered, metal is preferable. For the smaller sizes of weirs, the proper weir opening may be cut out of a single sheet of metal which may be fastened to the bulkhead. For the larger weirs crests and sides made from separate strips of metal having the edges filed true are more practical. This metal should be fairly heavy, to prevent the strips from bending and getting out of alignment easily. A more durable crest may be made of 1½-inch angle iron cut to the required lengths and set into the bottom and sides of the opening cut in the bulkhead. One face of the angle iron will be flush with the upstream side of the bulkhead and the other face will be fastened securely into the opening in the bulkhead. The edge over which the water will pass therefore will project 1½ inches from the opening in the bulkhead, and should be made true with squared edge.

If strips of wood are used for the crest and sides, they usually are fastened to the upstream face of the bulkhead for convenience, but in this case these strips must not be narrow, as this would give a pro-

jection the thickness of the strip, which will reduce the accuracy of the measurement of the water. With whatever type used, the joints formed by the sides and crest must fit nicely without leaving a crack and without causing an offset.

WEIR GAUGE.

The weir gauge, which is used to measure the depth of water flowing over the weir crest, may be an ordinary "ruler" or a hardwood stick graduated to feet and inches, but it is preferable to have it graduated to feet, tenths and hundredths of a foot. It should be set upstream from the weir notch a distance ("F" in fig. 1 and Table 1) at least four times the maximum depth of water ("H") to be run over the crest, or, if placed on the weir bulkhead, the distance "C," measured out from the end of the weir crest, should be at least two times the depth "H." If a complete weir box has been built, the gauge may be fastened to the bulkhead or the side of the box, as indicated in figure 1. If, instead of a weir box, an enlargement has been made in the ditch above the bulkhead, the gauge may be attached to a solid post set just far enough from the bank to insure that it always will be in the water. If a perma-

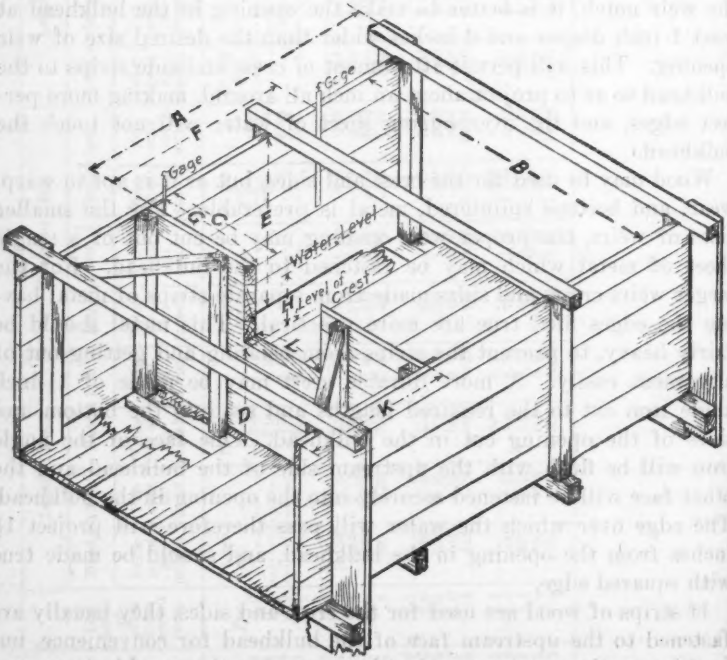

FIG. 1.—Plan of weir box.

nent gauge is not desired, a block or other solid support should be provided at the proper distance upon which to set a scale when taking readings.

The reason for placing the gauge as described is that the depth of water "H," from which the flow over weirs is computed, is measured vertically from the weir crest to the horizontal plane of the still-water surface in the weir pond upstream from the weir. There is a decided curving downward of the water surface near the weir notch, and it is necessary to get beyond the effect of this curvature, called "draw down," in order to get the correct depth of water "H."

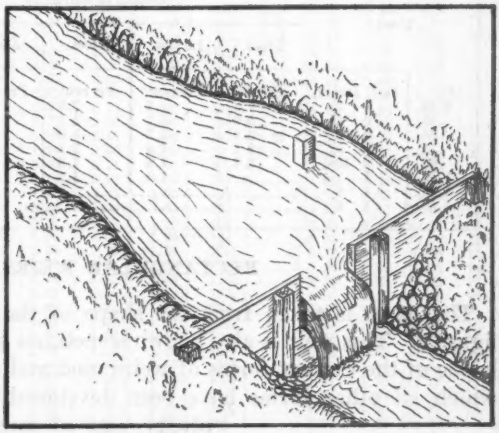

FIG. 2.—Weir notch and bulkhead in weir pond.

The zero of the gauge should be set level with the weir crest for rectangular and Cipolletti weirs, and with the lowest point in the 90° triangular notch, which has no real crest; but this level should not be determined by allowing the water to start to flow over the weir crest and marking the zero of the gauge from that water level, for, in fact, the water level must be appreciably higher than the crest before it will pour over the weir. It would be better to set the gauge with a good carpenter's level. Furthermore, before the beginning of each irrigation system, or oftener, the position of the weir crest and sides and the gauge should be checked carefully, for frost action or settlement in the wet soil may have altered their original position.

Where a hook gauge or an automatic recording gauge is to be used in connection with the weir, a water-tight still-box or gauge well should be provided outside of the weir box and connected to the weir box by means of a pipe laid through the bank below the level of the weir crest. The still-box should be placed upstream from the weir notch, a distance at least as great as shown in column "F" in Table 1, and should be enough deeper than the pipe to prevent silt accumulation from stopping the free passage of water through the pipe. It should be cleaned occasionally. The purpose of the box is to provide a still-water surface at the same level as the water in the weir box.

In order to obtain a correct measurement of the water flowing over a weir it is very necessary that the depth of water "H" be determined accurately. This means that the gauge must be placed accurately and read carefully. To show the error caused by misreading the gauge 0.01 foot, or slightly less than one-eighth inch, Table 4 is given.

TABLE 4.—*Percentage of error in discharge caused by 0.01 foot error in reading the head.*

Head.		Length of weir crest.					90° notch.
		1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.	
Feet.	*Feet. Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.20	0 2⅜	7.2	7.5	7.5	7.6	7.6	.....
.30	0 3⅝	5.0	5.1	5.1	5.6	4.8	8.5
.50	0 6	3.5	3.2	3.0	2.9	2.9	5.0
.70	0 8⅜	2.1	1.9	2.1	2.2	2.2	3.9
.90	0 10⅛	1.8	1.8	1.8	1.7	1.7	2.9
1.10	1 1⅛	.....	1.4	1.3	1.3	1.3	2.2
1.25	1 3	.....	.....	.....	1.1	1.1	2.1
1.50	1 6	.....	.....	.....	0.9	1.0	.....

RECTANGULAR WEIRS.

The name is taken from the shape of the weir notch, shown in figure 3. This weir is also known sometimes as the Francis weir. It is one of the earliest forms of weirs used and really is the type from which all other forms have been developed. Because of the simplicity, ease of construction and accuracy with which the crest and sides may be set with the implements ordinarily at hand, this type of weir demands a wider use than it has received in the past few years. It is equally as accurate as the other types. The crest is placed in a horizontal position and the sides extend vertically above the crest. The angle formed therefore is a right angle, which permits the weir to be set easily and accurately by means of a carpenter's square and level. The sides must be placed carefully to give the desired length along the crest. Table 5 gives the discharge over rectangular weirs from 1 to 4 feet in length, computed from the corrected formula.

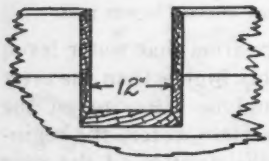

FIG. 3.—Rectangular weir.

TABLE 5.—*Discharge tables for rectangular weirs.*

Computed from the formula $Q=3.247\,lH^{1.48}-\frac{0.566\,l^{1.8}}{1+2\,l^{1.8}}\,H^{1.9}$.

Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.					Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.				
		1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	.86	10 1/16	2.46	3.72	5.01	7.59	10.19
.21	2 1/2	.312	.472	.632	.954	1.28	.87	10 3/16	2.50	3.79	5.10	7.72	10.36
.22	2 5/8	.335	.505	.677	1.02	1.37	.88	10 5/16	2.54	3.85	5.18	7.85	10.54
.23	2 3/4	.358	.539	.723	1.09	1.46	.89	10 7/16	2.58	3.92	5.27	7.99	10.71
.24	2 7/8	.380	.574	.769	1.16	1.55	.90	10 9/16	2.62	3.98	5.35	8.12	10.89
.25	3	.404	.609	.817	1.23	1.65	.91	10 11/16	2.67	4.05	5.44	8.25	11.07
.26	3 1/8	.428	.646	.865	1.31	1.75	.92	10 13/16	2.71	4.11	5.53	8.38	11.25
.27	3 1/4	.452	.682	.914	1.38	1.85	.93	10 15/16	2.75	4.18	5.62	8.52	11.43
.28	3 3/8	.477	.720	.965	1.46	1.95	.94	11	2.79	4.24	5.71	8.65	11.61
.29	3 1/2	.502	.758	1.02	1.53	2.05	.95	11 1/8	2.84	4.31	5.80	8.79	11.79
.30	3 5/8	.527	.796	1.07	1.61	2.16	.96	11 1/4	2.88	4.37	5.89	8.93	11.98
.31	3 3/4	.553	.836	1.12	1.69	2.26	.97	11 3/8	2.93	4.44	5.98	9.06	12.16
.32	3 13/16	.580	.876	1.18	1.77	2.37	.98	11 1/2	2.97	4.51	6.07	9.20	12.34
.33	3 15/16	.606	.916	1.23	1.86	2.48	.99	11 5/8	3.01	4.57	6.15	9.34	12.53
.34	4 1/16	.634	.957	1.28	1.94	2.60	1.00	12	3.06	4.64	6.25	9.48	12.72
.35	4 1/8	.661	.999	1.34	2.02	2.71	1.01	12 1/8	.....	4.71	6.34	9.62	12.91
.36	4 5/16	.688	1.04	1.40	2.11	2.82	1.02	12 1/4	.....	4.78	6.43	9.76	13.10
.37	4 7/16	.717	1.08	1.45	2.20	2.94	1.03	12 3/8	.....	4.85	6.52	9.90	13.28
.38	4 9/16	.745	1.13	1.51	2.28	3.06	1.04	12 1/2	.....	4.92	6.62	10.04	13.47
.39	4 11/16	.774	1.17	1.57	2.37	3.18	1.05	12 5/8	.....	4.98	6.71	10.18	13.66
.40	4 13/16	.804	1.21	1.63	2.46	3.30	1.06	12 3/4	.....	5.05	6.80	10.32	13.85
.41	4 15/16	.833	1.26	1.69	2.55	3.42	1.07	12 7/8	.....	5.12	6.90	10.46	14.04
.42	5 1/16	.863	1.30	1.75	2.65	3.54	1.08	12 15/16	.....	5.20	6.99	10.61	14.24
.43	5 1/8	.893	1.35	1.81	2.74	3.67	1.09	13 1/16	.....	5.26	7.09	10.75	14.43
.44	5 1/4	.924	1.40	1.88	2.83	3.80	1.10	13 1/8	.....	5.34	7.19	10.90	14.64
.45	5 3/8	.955	1.44	1.94	2.93	3.93	1.11	13 3/16	.....	5.41	7.28	11.04	14.83
.46	5 1/2	.986	1.49	2.00	3.03	4.05	1.12	13 1/4	.....	5.48	7.38	11.19	15.03
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.13	13 5/16	.....	5.55	7.47	11.34	15.22
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.14	13 3/8	.....	5.62	7.57	11.48	15.42
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.15	13 7/16	.....	5.69	7.66	11.64	15.62
.50	6	1.11	1.68	2.26	3.42	4.58	1.16	13 1/2	.....	5.77	7.76	11.79	15.82
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.17	13 9/16	.....	5.84	7.86	11.94	16.02
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.18	13 5/8	.....	5.91	7.96	12.09	16.23
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.19	13 11/16	.....	5.98	8.06	12.24	16.43
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.20	13 3/4	.....	6.06	8.16	12.39	16.63
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.21	13 13/16	.....	6.13	8.26	12.54	16.83
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.22	13 7/8	.....	6.20	8.35	12.69	17.03
.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.23	13 15/16	.....	6.28	8.46	12.85	17.25
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.24	14	.....	6.35	8.56	12.99	17.45
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.25	15	.....	6.43	8.66	13.14	17.65
.60	7 1/8	1.45	2.20	2.96	4.47	6.00	1.26	15 1/16	.....	.....	.....	13.30	17.87
.61	7 3/16	1.49	2.25	3.03	4.59	6.14	1.27	15 1/8	.....	.....	.....	13.45	18.07
.62	7 1/4	1.52	2.31	3.10	4.69	6.29	1.28	15 3/16	.....	.....	.....	13.61	18.28
.63	7 5/16	1.56	2.36	3.17	4.81	6.44	1.29	15 1/4	.....	.....	.....	13.77	18.50
.64	7 7/16	1.60	2.42	3.25	4.92	6.59	1.30	15 5/16	.....	.....	.....	13.93	18.71
.65	7 1/2	1.63	2.47	3.32	5.03	6.75	1.31	15 3/8	.....	.....	.....	14.09	18.92
.66	7 5/8	1.67	2.53	3.40	5.15	6.90	1.32	15 7/16	.....	.....	.....	14.24	19.12
.67	7 11/16	1.71	2.59	3.47	5.26	7.05	1.33	15 1/2	.....	.....	.....	14.40	19.34
.68	7 13/16	1.74	2.64	3.56	5.38	7.21	1.34	15 9/16	.....	.....	.....	14.56	19.55
.69	7 7/8	1.78	2.70	3.63	5.49	7.36	1.35	15 5/8	.....	.....	.....	14.72	19.77
.70	7 15/16	1.82	2.76	3.71	5.61	7.52	1.36	15 11/16	.....	.....	.....	14.88	19.98
.71	8 1/16	1.86	2.81	3.78	5.73	7.68	1.37	15 3/4	.....	.....	.....	15.04	20.20
.72	8 1/8	1.90	2.87	3.86	5.85	7.84	1.38	15 13/16	.....	.....	.....	15.20	20.42
.73	8 3/16	1.93	2.93	3.94	5.97	8.00	1.39	15 7/8	.....	.....	.....	15.36	20.64
.74	8 1/4	1.97	2.99	4.02	6.09	8.17	1.40	15 15/16	.....	.....	.....	15.53	20.86
.75	9	2.01	3.05	4.10	6.21	8.33	1.41	16 1/16	.....	.....	.....	15.69	21.08
.76	9 1/8	2.05	3.11	4.18	6.33	8.49	1.42	16 1/8	.....	.....	.....	15.85	21.29
.77	9 1/4	2.09	3.17	4.26	6.45	8.66	1.43	16 3/16	.....	.....	.....	16.02	21.52
.78	9 3/8	2.13	3.23	4.34	6.58	8.82	1.44	16 1/4	.....	.....	.....	16.19	21.74
.79	9 1/2	2.17	3.29	4.42	6.70	8.99	1.45	16 5/16	.....	.....	.....	16.34	21.96
.80	9 5/8	2.21	3.35	4.51	6.83	9.16	1.46	16 3/8	.....	.....	.....	16.51	22.18
.81	9 3/4	2.25	3.41	4.59	6.95	9.33	1.47	16 7/16	.....	.....	.....	16.68	22.41
.82	9 13/16	2.29	3.47	4.67	7.08	9.50	1.48	16 1/2	.....	.....	.....	16.85	22.64
.83	9 15/16	2.33	3.54	4.75	7.21	9.67	1.49	16 9/16	.....	.....	.....	17.01	22.85
.84	10 1/16	2.37	3.60	4.84	7.33	9.84	1.50	18	.....	.....	.....	17.17	23.08
.85	10 3/16	2.41	3.66	4.92	7.46	10.01							

CIPOLLETTI WEIRS.

This type of weir is trapezoidal in shape, but the name "Cipolletti" is that of the Italian engineer who proposed its use. As shown in figure 4, the crest of the weir must be level, and the sides placed on a slope of 1 to 4, meaning one unit horizontal to four units vertical. The notch therefore is larger than a rectangle with the same crest length.

It is seen readily that the Cipolletti type of weir, or in fact any weir having sloping sides, is neither so easy to construct nor so easy to check later for accuracy as is the rectangular weir. The great popularity of the Cipolletti weir is due somewhat to its having been proposed at a time when the use of weirs for measuring irrigation water was being considered, but principally because the angle which the sides make with the crest was supposed to make the flow over the weir proportional to the length of the crest. In other words, the flow for a certain head on a 2-foot weir was supposed to be twice the flow over a 1-foot weir for the same depth of water, which would require but a simple weir table for field use. Recent experiments, however, prove that the flow over Cipolletti weirs is not proportional to the length of the crest, which apparently refutes the principal argument in its favor. However, if the sides are placed properly with respect to the crest, and other conditions are observed fully the flow can be measured as accurately over a Cipolletti weir as over a rectangular weir, if the accompanying weir tables, or formula, are used. It is all right, therefore, to use a Cipolletti weir if constructed properly, but where a weir is to be constructed, the rectangular should be chosen in preference to the Cipolletti type. Table 6 gives the discharge over Cipolletti weirs from 1 to 4 feet in length, computed from the corrected formula.

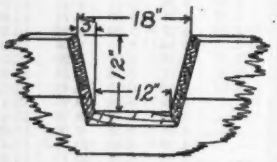

FIG. 4.—Cipolletti or trapezoidal weir.

TABLE 6.—*Discharge tables for Cipolletti weirs.*

Computed from the formula $Q=3.247\ lH^{1.48}-\frac{0.566\ l^{1.8}}{1+2\ l^{1.8}}H^{1.9}+0.609\ H^{2.5}$.

Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.					Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.				
		1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
0.20	2⅜	0.30	0.45	0.60	0.90	1.20	.86	10 5/16	2.87	4.14	5.43	8.01	10.60
.21	2½	.32	.48	.64	.97	1.29	.87	10 7/16	2.93	4.22	5.52	8.15	10.79
.22	2⅝	.35	.52	.69	1.04	1.38	.88	10½	2.98	4.29	5.62	8.30	10.98
.23	2¾	.37	.55	.74	1.11	1.47	.89	10 9/16	3.04	4.37	5.72	8.44	11.17
.24	2⅞	.39	.59	.79	1.18	1.57	.90	10⅝	3.09	4.45	5.82	8.59	11.36
.25	3	.42	.63	.84	1.25	1.67	.91	10 11/16	3.15	4.53	5.92	8.73	11.55
.26	3⅛	.45	.67	.89	1.33	1.77	.92	10¾	3.20	4.60	6.02	8.88	11.74
.27	3¼	.47	.70	.94	1.40	1.87	.93	10 13/16	3.26	4.68	6.13	9.03	11.94
.28	3⅜	.50	.74	.99	1.48	1.97	.94	10⅞	3.32	4.76	6.23	9.17	12.13
.29	3½	.53	.79	1.04	1.56	2.08	.95	10 15/16	3.37	4.84	6.33	9.32	12.33
.30	3⅝	.56	.83	1.10	1.64	2.19	.96	11	3.43	4.92	6.44	9.48	12.53
.31	3¾	.59	.87	1.15	1.73	2.30	.97	11 1/16	3.49	5.00	6.55	9.62	12.72
.32	3 13/16	.61	.91	1.21	1.80	2.41	.98	11⅛	3.55	5.09	6.64	9.78	12.92
.33	3⅞	.64	.95	1.27	1.89	2.52	.99	11 3/16	3.61	5.17	6.75	9.93	13.12
.34	4 1/16	.67	1.00	1.32	1.98	2.64	1.00	12	3.67	5.25	6.86	10.08	13.32
.35	4⅛	.70	1.04	1.38	2.07	2.75	1.01	12⅛	.....	5.33	6.96	10.24	13.53
.36	4 3/16	.73	1.09	1.44	2.16	2.87	1.02	12¼	.....	5.42	7.07	10.40	13.73
.37	4¼	.77	1.13	1.50	2.25	2.99	1.03	12⅜	.....	5.50	7.18	10.55	13.94
.38	4 5/16	.80	1.18	1.57	2.34	3.11	1.04	12½	.....	5.59	7.29	10.71	14.15
.39	4⅜	.83	1.23	1.63	2.43	3.24	1.05	12⅝	.....	5.67	7.40	10.87	14.35
.40	4 7/16	.87	1.28	1.69	2.53	3.36	1.06	12¾	.....	5.76	7.51	11.03	14.56
.41	4½	.90	1.32	1.76	2.62	3.49	1.07	12 13/16	.....	5.84	7.62	11.18	14.76
.42	4 9/16	.93	1.37	1.82	2.72	3.61	1.08	12⅞	.....	5.93	7.73	11.35	14.98
.43	4⅝	.97	1.42	1.89	2.81	3.74	1.09	12 15/16	.....	6.02	7.84	11.51	15.19
.44	4¾	1.00	1.47	1.95	2.91	3.87	1.10	13	.....	6.11	7.96	11.68	15.41
.45	4 13/16	1.04	1.53	2.02	3.01	4.01	1.11	13 1/16	.....	6.20	8.07	11.84	15.62
.46	4⅞	1.07	1.58	2.09	3.11	4.14	1.12	13⅛	.....	6.29	8.18	12.00	15.84
.47	4 15/16	1.11	1.63	2.16	3.21	4.28	1.13	13 3/16	.....	6.37	8.29	12.16	16.04
.48	5	1.15	1.68	2.23	3.32	4.41	1.14	13¼	.....	6.46	8.41	12.33	16.26
.49	5⅛	1.18	1.74	2.30	3.42	4.55	1.15	13 5/16	.....	6.56	8.53	12.50	16.48
.50	6	1.22	1.79	2.37	3.53	4.69	1.16	13⅜	.....	6.65	8.65	12.67	16.70
.51	6⅛	1.26	1.85	2.44	3.64	4.83	1.17	13 7/16	.....	6.74	8.76	12.84	16.93
.52	6¼	1.30	1.90	2.51	3.74	4.97	1.18	13½	.....	6.83	8.88	13.01	17.15
.53	6⅜	1.34	1.96	2.59	3.85	5.12	1.19	13 9/16	.....	6.93	9.10	13.18	17.37
.54	6½	1.38	2.02	2.66	3.96	5.26	1.20	13⅝	.....	7.02	9.12	13.35	17.59
.55	6⅝	1.42	2.07	2.74	4.07	5.41	1.21	13¾	.....	7.11	9.24	13.52	17.81
.56	6¾	1.46	2.13	2.81	4.18	5.56	1.22	13 13/16	.....	7.20	9.36	13.69	18.03
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.23	13⅞	.....	7.30	9.48	13.87	18.27
.58	6⅞	1.54	2.25	2.97	4.41	5.86	1.24	13 15/16	.....	7.40	9.60	14.04	18.49
.59	6 15/16	1.58	2.31	3.05	4.53	6.01	1.25	14	.....	7.49	9.72	14.21	18.71
.60	7 1/16	1.62	2.37	3.13	4.64	6.17	1.26	14⅛	.....	.....	.....	14.39	18.95
.61	7⅛	1.67	2.43	3.20	4.76	6.32	1.27	14¼	.....	.....	.....	14.56	19.17
.62	7 3/16	1.71	2.49	3.28	4.88	6.47	1.28	14⅜	.....	.....	.....	14.74	19.41
.63	7¼	1.75	2.55	3.37	5.00	6.63	1.29	14½	.....	.....	.....	14.92	19.65
.64	7 5/16	1.80	2.62	3.45	5.12	6.79	1.30	14⅝	.....	.....	.....	15.11	19.88
.65	7⅜	1.84	2.68	3.53	5.24	6.95	1.31	14¾	.....	.....	.....	15.29	20.12
.66	7 7/16	1.89	2.75	3.61	5.36	7.11	1.32	14 13/16	.....	.....	.....	15.46	20.34
.67	7½	1.93	2.81	3.70	5.48	7.28	1.33	14⅞	.....	.....	.....	15.64	20.58
.68	7 9/16	1.98	2.87	3.79	5.61	7.44	1.34	14 15/16	.....	.....	.....	15.82	20.82
.69	7⅝	2.02	2.94	3.87	5.73	7.61	1.35	15 1/16	.....	.....	.....	16.01	21.06
.70	7¾	2.07	3.01	3.95	5.86	7.77	1.36	15⅛	.....	.....	.....	16.19	21.29
.71	7 13/16	2.12	3.07	4.04	5.99	7.94	1.37	15 3/16	.....	.....	.....	16.37	21.53
.72	7⅞	2.16	3.14	4.13	6.12	8.11	1.38	15¼	.....	.....	.....	16.57	21.78
.73	7 15/16	2.21	3.21	4.22	6.24	8.28	1.39	15 5/16	.....	.....	.....	16.75	22.02
.74	8	2.26	3.28	4.31	6.38	8.45	1.40	15⅜	.....	.....	.....	16.94	22.27
.75	9	2.31	3.35	4.40	6.51	8.62	1.41	15 7/16	.....	.....	.....	17.13	22.51
.76	9⅛	2.36	3.42	4.49	6.64	8.80	1.42	15½	.....	.....	.....	17.31	22.75
.77	9¼	2.41	3.49	4.58	6.77	8.97	1.43	15 9/16	.....	.....	.....	17.51	23.01
.78	9⅜	2.46	3.56	4.67	6.90	9.15	1.44	15⅝	.....	.....	.....	17.70	23.26
.79	9½	2.51	3.63	4.76	7.04	9.33	1.45	15¾	.....	.....	.....	17.89	23.50
.80	9⅝	2.56	3.70	4.85	7.18	9.51	1.46	15 13/16	.....	.....	.....	18.08	23.75
.81	9¾	2.61	3.77	4.95	7.31	9.69	1.47	15⅞	.....	.....	.....	18.28	24.01
.82	9 13/16	2.66	3.84	5.04	7.45	9.87	1.48	15 15/16	.....	.....	.....	18.47	24.26
.83	9⅞	2.71	3.92	5.14	7.59	10.05	1.49	16	.....	.....	.....	18.66	24.50
.84	10 1/16	2.77	3.99	5.23	7.73	10.23	1.50	18	.....	.....	.....	18.85	24.75
.85	10⅛	2.82	4.07	5.33	7.87	10.42							

90° TRIANGULAR-NOTCH WEIRS.

This type of weir deserves to be more widely used than at present for the measurement of small quantities of water to the irrigator. If the fall is available it may be used for flows as great as 14 second-feet, which would be obtained with a depth of practically 2 feet of water above the vertex, or lowest point, of the angle formed by the sides. However, conditions usually are not favorable for its use for such large heads, and Table 7 gives the discharge for heads up to 1.25 feet. Since the sides meet at a point with no length of crest, a small flow of water that would not pass over one of the other weirs without adhering to the crest and therefore making the measurement worthless, will flow free in the 90° triangular notch and may be measured accurately. The 90° triangular notch is especially applicable from the smallest flow up to 2 or 3 cubic feet per second. Because of the greater depth of water required for this type of weir to discharge a given quantity of water, and the consequent greater loss of grade, one of the other types of weirs usually will be better adapted to large quantities of water.

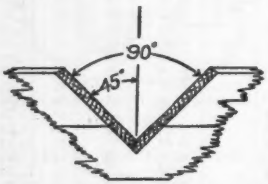

FIG. 5.—Ninety-degree triangular notch weir.

Experiments have shown that the rectangular and Cipolletti weirs with 6-inch crest lengths do not follow the same laws of discharge as the longer weirs, and the discharge formulas given in this bulletin for these weirs do not apply to weirs with a crest length of 6 inches. Therefore, where only a small flow of water is to be measured the use of the 90° triangular notch is especially recommended.

The sides of the 90° triangular notch may be set readily by means of a carpenter's square and level. The notch can be marked out properly by placing the point of the angle between the arms of a carpenter's square at a point which is to be the bottom of the notch and adjusting the square so that the same figures on both arms of the square are at the edge of the board, then if the board is set level the notch will be in the proper position. The sides, therefore, have the same slope.

Table 7 gives the discharge over the 90° triangular notch, computed from the corrected formula.

TABLE 7.—*Discharge table for 90° triangular notch.*

Computed from the formula $Q=2.49\ H^{2.48}$.

Head in feet.	Head in inches.	Discharge in second-feet (Q).	Head in feet.	Head in inches.	Discharge in second-feet (Q).	Head in feet.	Head in inches.	Discharge in second-feet (Q).
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 1/8	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 1/8	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 3/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 5/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 3/8	.790	.98	11 3/4	2.37
.29	3 1/2	.115	.64	7 7/16	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 1/2	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 5/8	.887	1.01	12 1/8	2.55
.32	3 13/16	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 1/8	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
.35	4 1/8	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 3/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 1/4	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 5/16	.226	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 1/2	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 3/8	.256	.75	9	1.22	1.10	13 1/8	3.15
.41	4 1/2	.272	.76	9 1/8	1.26	1.11	13 3/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 1/4	3.30
.43	5 1/8	.306	.78	9 3/8	1.34	1.13	13 5/16	3.37
.44	5 1/4	.324	.79	9 1/2	1.39	1.14	13 7/16	3.44
.45	5 3/8	.343	.80	9 5/8	1.43	1.15	13 1/2	3.52
.46	5 1/2	.362	.81	9 3/4	1.48	1.16	13 5/8	3.59
.47	5 5/8	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 3/4	.403	.83	9 15/16	1.57	1.18	14 1/8	3.75
.49	5 7/8	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 1/8	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 3/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 5/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 3/8	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 11/16	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

UNITS OF MEASURE.

The *cubic-foot per second*, called second-foot, is a unit of measure for flowing water. When a stream discharges 1 cubic foot of water in one second there is a second-foot flow.

The *acre-foot* is a unit of measure for standing water, and is that volume which will cover 1 acre 1 foot deep. An acre-inch is $\frac{1}{12}$ of an acre-foot, or the volume which will cover 1 acre to a depth of 1 inch.

The *miner's inch* is unsatisfactory and rapidly losing favor as a unit for measuring water, because it is not a definite quantity. It varies with the conditions under which it is used, and therefore is being replaced by the second-foot. In several of the Western States the miner's inch has been defined by law as being a certain fractional part of a second-foot, and these values are given in the accompanying table of hydraulic equivalents.

TABLE OF HYDRAULIC EQUIVALENTS.

1 cubic foot equals 7.48 gallons, or approximately 7½ gallons.
1 cubic foot of water weighs approximately 62½ pounds.
1 cubic foot per second equals 448.83 gallons per minute, or approximately 450 gallons per minute.
1 cubic foot per second flowing for 1 hour equals approximately 1 acre-inch.
1 cubic foot per second flowing for 12 hours equals appromiately 1 acre-foot.
1 cubic-foot per second flowing for 24 hours equals approximately 2 acre-feet.
1 acre-foot equals 43,560 cubic feet, equals 325,851 gallons.
1,000,000 cubic feet equals 22.95 acre-feet.

In California, Nevada, and Montana 1 miner's inch (statutory inch) equals $\frac{1}{40}$ of 1 cubic foot per second.

In Utah, Idaho, and Arizona 1 miner's inch (statutory inch) equals $\frac{1}{50}$ of 1 cubic foot per second.

In Colorado it is generally assumed that 1 miner's inch (statutory inch) equals 1/38.4 of 1 cubic foot per second.

SOME PUBLICATIONS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE RELATING TO IRRIGATION.

AVAILABLE FOR FREE DISTRIBUTION.

Wood Pipe for Conveying Water for Irrigation (Department Bulletin 155).
Irrigation in Florida (Department Bulletin 462).
Spray Irrigation (Department Bulletin 494).

FOR SALE BY THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

How to Build Small Irrigation Ditches (Farmers' Bulletin 158). Price, 5 cents.
Use of Alcohol and Gasoline in Farm Engines (Farmers' Bulletin 277). Price, 5 cents.
Practical Information for Beginners in Irrigation (Farmers' Bulletin 263). Price, 5 cents.
Irrigation of Alfalfa (Farmers' Bulletin 373). Price, 5 cents.
Irrigation of Sugar Beets (Farmers' Bulletin 392). Price, 5 cents.
Use of Windmills in Irrigation in Semiarid West (Farmers' Bulletin 394). Price, 5 cents.
Irrigation of Grain (Farmers' Bulletin 399). Price, 5 cents.
Irrigation of Orchards (Farmers' Bulletin 404). Price, 5 cents.
Irrigation Practice in Rice Growing (Farmers' Bulletin 673). Price, 5 cents.
Progress Report of Cooperative Irrigation Experiments at California University Farm, Davis, Cal., 1909–1912 (Department Bulletin 10). Price, 5 cents.
Gate Structures for Irrigation Canals (Department Bulletin 115). Price, 20 cents.
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Delivery of Water to Irrigators (Office of Experiment Stations Bulletin 229). Price, 15 cents.
Use of Underground Water for Irrigation at Pomona, Cal. (Office of Experiment Stations Bulletin 236). Price, 20 cents.
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BERMUDA GRASS

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Agronomist, Office of Forage-Crop Investigations

SEE REVISED EDITION

FARMERS' BULLETIN 814

UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Plant Industry

WM. A. TAYLOR, Chief

Washington, D. C. May, 1917

BERMUDA grass is the most important perennial grass in the Southern States. It was introduced into the United States at least as early as 1806.

Besides the common Bermuda grass, there are several varieties, the most important of which are the Giant, characterized by a very large growth, and St. Lucie grass, similar to ordinary Bermuda grass, but lacking underground rootstocks.

Bermuda grass grows well mixed with lespedeza for a summer crop. Bur clover, black medic, and hairy vetch as winter crops alternate well with it.

The best Bermuda-grass pastures of the South will usually carry two head of cattle per acre for eight months of the year. On poor soils the carrying capacity is not more than one cow per acre.

On rich bottom land Bermuda grass grows tall enough to cut for hay. Under exceptional circumstances three or more cuttings may be secured in a season, giving total yields of from 6 to 10 tons of hay per acre. It will grow well on soils so alkaline that most other field crops, as well as fruits, will fail.

The feeding value of Bermuda-grass hay compares closely with that of timothy hay.

Bermuda grass frequently is used to bind levees and to prevent hillsides from washing.

The grass usually can be eradicated by growing two smother crops, a winter one of oats or rye, followed by a summer crop of cowpeas or velvet beans.

BERMUDA GRASS.

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INTRODUCTION.

Bermuda grass [1] is the most common and most valuable pasture plant in all the Southern States, being of the same relative importance in that region that Kentucky bluegrass is in more northern States. In many sections of the South it is one of the best grasses for hay, and it is the most common grass used for lawn purposes.

It makes a vigorous and persistent growth in nearly all the warmer parts of the world, and its value depends on the region in which it is grown and the purpose for which it is to be used. In India it is known as sacred grass and is there believed to have been the gift of some benevolent deity for the support of the cows, which are also held as sacred in that country. In sharp contrast with that, however, in the southwestern part of the United States it is known as devil grass on account of the trouble which it gives in irrigated fields and on ditch banks.

DESCRIPTION OF BERMUDA GRASS.

Bermuda grass is a perennial, spreading by runners or by rootstocks, or by both, and also by seeds. The runners are usually from a few inches to 3 or 4 feet, though sometimes more than 20 feet in length, creeping over the surface of the ground and often rooting at the joints. The erect flower-bearing branches are usually 6 to 12 inches in height, though reaching 2 feet or more in some varieties; the leaf blades are narrow, flat, 1 to 4 inches in length, each bearing a ring of minute white hairs at the base; the flowers are in slender spikes, three to six in a cluster, radiating like those of crab-grass, each spike 1 to 2 inches long. (Fig. 1.)

[1] *Cynodon dactylon* or *Capriola dactylon*.

The stems of this grass are peculiar in that they often appear to have from two to four leaves at each joint. There is really only one leaf at each joint, but in many cases two to four contiguous joints are very short and so bear as many leaves close together as there are short joints. The two or more short joints are succeeded by a longer joint, 1 to 3 inches in length, which, in turn, may be followed by two or more short joints. While this arrangement of alternating long and short joints is very common, it is far from being uniform.

FIG. 1.—Bermuda grass.

HISTORY.

Bermuda grass is undoubtedly a native of the Old World, probably of India, but it is now common in all tropical and subtropical parts of the world. It is not known when it made its first appearance in America, but in Mease's Geological Account of the United States, published in 1807, it is mentioned as one of the most important grasses in the Southern States. It is now common in all parts of the United States from Virginia to Florida and westward to Arizona and California.

In the United States it is commonly known as Bermuda grass, which suggests that it may have come to America by way of the islands of that name, though there is no definite published record of such a source. In some localities it is known as wire-grass, scutch-grass, dog's-tooth, or Bahama grass, and in California and Arizona it is often called devil grass. In Australia it is commonly known as couch or Indian couch. In the Hawaiian Islands it is known as manienie, while in India it is called doob, and in southern India hariali. The many names which have been given to it in different parts of the world show that it has a wide distribution and that it has long been regarded as an important plant.

There is a grass which is often called "water Bermuda" or "ditch Bermuda."[1] It is better known as knot-grass, or ditch-grass, as it commonly grows on the sides and bottoms of ditches and on other damp soils, where it gives a considerable amount of grazing but is of no value for hay. It is easily distinguished from true Bermuda grass, which has three to six seed spikes, while this has but two.

CLIMATIC ADAPTATIONS.

Bermuda grass requires warm weather during its growing season. It bears intense summer heat without injury, but is seriously injured by a moderate degree of cold and is seldom persistent where the temperature often falls much below zero F., though the rootstocks may withstand a somewhat lower temperature. It often winterkills in western Kentucky and Tennessee. It usually does not bear heavy freezing, though it has lived through a temperature of −10° F. in Kentucky and in Washington, D. C., and −18° F. in Oklahoma. On the Atlantic coast, southeastern Virginia is about the northern limit of its profitable growth, and there it is not sufficiently aggressive to interfere with the growth of alfalfa. On the Pacific coast it makes little growth north of California.

Bermuda grass does best with abundant moisture, but will not grow well where the ground is not thoroughly drained. In the arid region of the Southwest it is of little value if not irrigated, not making as vigorous a growth as curly mesquite, buffalo grass, and some other native species. It bears a long and hot summer with little injury, though it makes little growth when the weather is very dry and it is not irrigated. It will bear flooding for some weeks, but will not grow well where the soil is constantly saturated with stagnant water.

It does not bear shading well, even when all other conditions are favorable, and planters often take advantage of this fact to secure its eradication by growing smother crops.

ADAPTATIONS TO SOIL.

Bermuda grass will grow well on almost any soil which is fertile and not too wet, but better on soils that are heavy than on those which are light and sandy. On the latter it is likely to be crowded out by carpet grass or other native species. It will grow satisfactorily on light and sandy soils when they are well fertilized with cottonseed meal, dried blood, or some other nitrogenous fertilizer, but it does not do well on soils containing little humus or nitrogen. It will grow well on soils so alkaline that most other field crops, as well as fruits, will fail, as has been shown in California and other Southwestern States. The presence or absence of lime seems to have little effect on the amount of its growth. Careful trials at the Mississippi and Georgia agricultural experiment stations have shown no beneficial effects

[1] *Paspalum distichum.*

from the application of lime in any form, though similar tests at the Tennessee station have indicated a moderate benefit. While the presence or absence of lime may not influence the yield, it apparently influences the quality. Live-stock dealers and butchers in Mobile and New Orleans have stated repeatedly that they can recognize cattle that have been raised in a limestone region and that these cattle always bring the highest price.

Bermuda grass does best on a fertile soil which is fairly moist, well drained, and rich in humus and nitrogen.

DISTRIBUTION IN THE UNITED STATES.

The accompanying map (fig. 2) shows approximately the region in which Bermuda grass has become naturalized and is more or less profitable. The shaded portion marks the region where the grass is grown most extensively. In warm valleys and specially favorable locations it often grows for some distance north of the limit shown. Bermuda grass grows well in many parts of California, but is utilized there mainly for lawns, rarely for hay or pasture. It is often a troublesome weed in alfalfa fields and is objectionable on the banks of irrigation ditches, as its runners often spread so as to obstruct the flow of water. East of the one hundredth meridian the northern limit of its profitable growth is about the same as the southern limit for the growth of Kentucky bluegrass, though in many places the ground is occupied by a more or less uneven mixture of the two. It is not common north of the Potomac and Ohio Rivers or north of the Missouri River east of Kansas City.

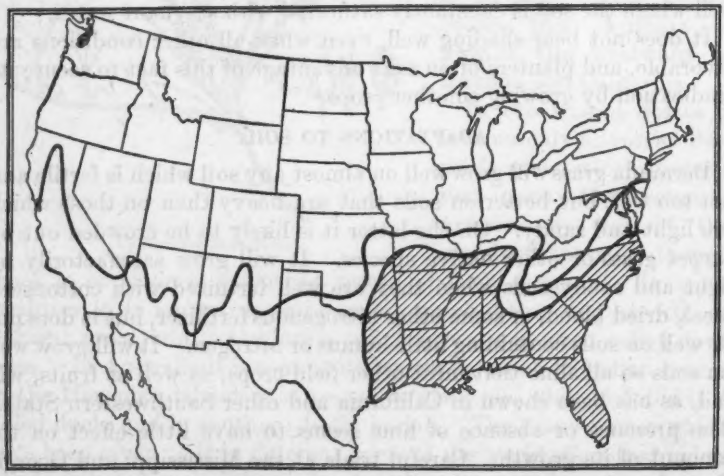

FIG. 2.—Map of the United States, showing the distribution of Bermuda grass. The upper line indicates its northern limit, but the grass is of most value in the shaded area.

VARIETIES.

Bermuda grass is valued principally for two purposes—for the production of hay and pasture and for use on lawns. For hay and pasture the best variety is that which makes the strongest growth, while for lawns the most satisfactory is one which is dwarf in growth and covers the ground with a dense mat of turf. For use in the northern parts of the Bermuda-grass region the variety planted for any purpose should be one which is not killed by ordinary freezes, while the ability to resist cold needs less consideration farther south. The variety to be planted should be selected to suit the purpose and locality for which it is wanted.

The soil on which Bermuda grass is grown and the treatment which it receives cause great variations in its growth. Plants which may make a rank, erect growth, a foot or more in height and with long leaves, when grown on a rich and moist soil may make only a flat and spreading growth, with stems only 2 or 3 inches high and with very short leaves, when transplanted to a hard clay soil. There are, however, a few varieties which are quite distinct from others wherever they may be planted.

The most common variety, the one which is in almost universal use wherever Bermuda grass is grown, produces stems only about a foot or less in height, though varying greatly. It produces abundant rootstocks, which often run several inches below the surface of the ground, and also makes surface runners, which may be from a few inches to several feet in length.

The most rank-growing sort yet found is Giant Bermuda grass,[1] introduced from Brazil a few years ago. On a rich and moist soil it often makes runners 20 feet or more in length, with an abundance of erect stems 2 feet or more in height, affording two or three annual cuttings and yielding more than any other variety yet tested. It rarely produces seed heads and has few or no underground rootstocks. Another form from southern Florida is very similar in growth, but has shorter runners and produces seed heads very abundantly. While both these varieties make heavy yields for hay and grazing, they are too coarse for use on a lawn. St. Lucie grass is another variety, with no underground rootstocks. This variety is rather dwarf in growth, seldom more than 6 inches in height, with slender stems and small leaves. It is one of the best sorts for lawns and dooryards. It is common in Florida and is not hardy as far north as middle Georgia. Its growth is too dwarf to make it profitable for hay, but it recovers quickly after frosts and so is valuable for pastures and lawns.

Many other varieties may be separated from the common Bermuda grass of the fields, the most important differences being in rankness

[1] *Cynodon dactylon* var. *maritimus*.

of growth, the presence or absence of underground rootstocks, hardiness, and other characters of less importance. When it is desired to propagate any peculiar form which may be found, the plants should be increased by the division of the runners or rootstocks, as seeds rarely produce exact duplicates of the parent form.

There seems to be little relation between the growth of rootstocks underground and the growth of the stems above ground. In general, however, those varieties making deep underground rootstocks stand more severe freezes than those with only surface runners and so are more desirable for planting in the northern part of the Bermuda-grass region. The varieties with only surface runners are more easily killed when it is desired to exterminate the grass and use the land for other crops.

SEED PRODUCTION.

Bermuda grass seeds freely in southern California, Arizona, and New Mexico, and from these States part of the commercial supply of seed is now obtained. Tests of seeds grown in California and Arizona have shown a germination of 95 per cent, which is a much higher percentage than is obtained from most imported seed. Many years ago all the seed used in this country was imported from Australia and sold at a very high price, but now that home-grown seed has proved fully as good the price has steadily declined until seed may be bought for about 50 cents a pound.

Bermuda grass also seeds occasionally much farther east, good seed having been found in southern Texas, southwestern Louisiana, North Carolina, and even as far north as Washington, D. C. It does not seed well in any region of heavy rainfall, as on the Gulf coast, and it needs a season of considerable heat and dry weather for the best seed development. It is probable that the occasional development of seed is an important factor in the spread of the grass in all parts of the country where it occurs.

PROPAGATION.

Bermuda grass may be propagated either by seeds or by "roots" or cuttings.

As the seeds are very light and small, the ground should be put in the finest possible condition before they are sown. The sowing should not be done until late in the spring, when the soil has become fairly warm. Immediately after cotton planting is generally the best season for the work. When good seed is used 5 pounds per acre are sufficient. Before sowing, it should be mixed with cotton-seed meal, wood ashes, or some similar material—even fine soil will answer—to increase the bulk and so secure a more even distribution over the field. The seeding should always be broadcast and can

be done either by hand or by using a wheelbarrow seeder. In any case it is better to sow only half the seed the first time the field is gone over, and then the other half while going over the field at right angles to the direction in which the first half was sown, so as to cover skips and balks. If possible, a roller should be used for covering the seeds, but if that is not available a light smoothing harrow or a drag made of brush may be employed. The covering should always be very shallow; therefore the use of a roller is of great advantage, as it packs and firms the soil without covering the seeds too deeply.

When the seed is planted in the spring on well-prepared soil, the plants will cover the ground by midsummer and will give a cutting for hay or a considerable amount of pasturage in the fall. It is useless to plant seed on poorly prepared land. Ground seeded in the spring should not be pastured until the sod has become so dense that it will not be injured by trampling. When bare spots are found they can be filled in easily by transplanting "roots" from the thicker places at any time during the summer.

Roots and cuttings are used in propagation much more commonly than seeds. In planting, fresh sods about an inch in thickness should be taken up, either by using a spade or a plow, and then torn into very small pieces for distribution. It is common practice to plow furrows 4 to 6 feet apart, then drop pieces of sod every 2 or 3 feet and cover with the foot. This method of planting is very inexpensive and answers well where the land is to be used as a pasture, but it leaves the surface of the ground too rough and uneven for a good meadow. When the entire surface is plowed, the pieces may be dropped 2 or 3 feet apart and pushed into the soil with a forked stick, such as is used in planting sweet potatoes, and then stepped on, to firm the soil and prevent drying out.

Another method is to plow the old sod very shallow, harrow until the roots are well loosened, rake into piles or windrows, and load into a wagon. The wagon is then driven across the freshly prepared field in which the planting is to be done and the roots dropped about 2 feet apart in the wheel tracks and covered with the foot. The ground should be gone over twice, lapping the spaces, so that the rows will be only half as far apart as the distance between the wheels. An ordinary wagon box will hold enough roots to plant 1 to 2 acres, depending on how finely the roots are divided and how carefully the work is done. When planted in this way the grass will cover the ground in a few weeks and the total expense, including the preparation of the ground, need not be more than $5 per acre for the labor employed.

When a field is to be planted for a meadow it should be prepared as carefully as for seeding. Since it is to be a permanent field for

mowing and will be used many years for that purpose, all bumps and hollows should be smoothed off, so that water can not stand in low spots and the mowing machine and rake may run over it smoothly and not be injured by racking. While Bermuda grass will make some sort of a growth in almost any field it can never make a satisfactory meadow if the ground is not well prepared and made smooth before planting. As good soil and as thorough preparation are needed to make a good meadow as to make a good crop of corn or cotton.

When roots are used for planting they should always be protected from the sun as much as possible. When loaded into a wagon they should be wet down and covered with a blanket or old sacks to prevent them from becoming dry.

As is stated elsewhere, different varieties of Bermuda grass vary greatly in hardiness. Some are killed by very moderate frosts, while others, usually those with deep-running rootstocks, bear heavy freezes without injury. For this reason it is safer in the northern parts of the Bermuda region to propagate from near-by old fields, as these plants have proved themselves hardy. While seeds may make an abundance of thrifty plants, many of them are likely to be killed by the first severe winter. Farther south, seeds may be used with greater safety.

Whatever method may be followed in planting it will often be necessary to mow the field a few weeks afterwards to prevent weeds from shading and choking out the young Bermuda-grass plants.

PASTURE VALUE.

Bermuda grass is the foundation of all good permanent pastures in the South. It is the best pasture grass in the region from the Carolinas westward to California on soils of fair fertility and with even moderate rainfall, although on the very dry lands of New Mexico and Arizona it is less productive than curly mesquite and buffalo grasses. It bears heavy grazing and trampling with little injury, recovers quickly when grazed down, and is eaten greedily by all kinds of live stock. Even the rootstocks are so tender and juicy that they are well liked by hogs. It should be used as the principal grass in the making of all permanent pastures in the region shaded in figure 2, and should be supplemented by whatever other grazing plants grow well in each special locality.

As it is killed to the ground by the first severe frost, it usually gives good grazing only through the summer and fall months, though in the southern portions of Florida and Texas it frequently remains green and gives good feed through the entire year. In California it furnishes good grazing about nine months. In Oklahoma it is green from April to October. In Virginia Bermuda grass and lespe-

deza give the best grazing on the low lands. On sandy soils Bermuda grass does not bear trampling and close grazing as well as on heavier soils. When used for pasture it should be kept closely grazed. If the stems are allowed to become too old they get so dry and wiry that live stock do not relish them. Where there is not sufficient live stock in the pasture to keep the grass well grazed down it will often pay to harvest for hay and so secure a fresh growth for pasturing, which is more palatable and more nutritious than the older stems.

The number of live stock which can be carried on an acre of Bermuda-grass pasture varies widely with the soil and climate. On average soils such pasture will carry about one steer to the acre during the growing season, though on thin and hard clay soils as much as 2 acres per steer may be required. In specially favorable localities in the extreme south on very fertile soils 1 acre of Bermuda-grass pasture may support three or four steers nine or ten months. The Mississippi Agricultural Experiment Station says this pasture will support at least one steer per acre on ordinary soils and double that number on soils more favorable for its growth. On the rich alluvial soils formed by the overflows of the Mississippi River the growth of the grass is much more rank, some cattle growers in that region claiming that they can graze as many as six steers per acre for nine months and that the pastures will then support one to three steers per acre during the other three months. Of course, such yields are very exceptional and should not be considered in estimating the value of Bermuda grass on ordinary soils.

Bermuda grass does not mix well with other grasses, as it either makes a clean sod by itself or is crowded out by other plants better suited to the particular locality. This is especially true on the rather sandy lands along the coast where carpet grass is abundant. There the sod is often spotted, the heavier and richer spots where a stump has been removed or a little fertilizer dropped being densely covered with Bermuda grass, while adjacent spots may be covered with an equally dense mat of carpet grass. Whenever it is planted on a soil suited to its growth, Bermuda grass will crowd out most other grasses and soon occupy the entire field, but the crowding out is usually in very definite areas and not by a gradual mixing.

There are, however, a few legumes which grow well when planted on the same ground with Bermuda grass and add largely to its pasture value. Among the best of these are lespedeza, bur clover, black medic, and melilotus. Lespedeza grows only in the summer and fall, bur clover and black medic only in the winter and spring, while melilotus gives more or less grazing through the entire year.

Lespedeza is the most valuable species for summer and fall grazing and is the best legume which can be used on fairly heavy soils, but it

makes only a weak growth on the sandy soils in the piny woods region. It grows well on clay soils which are too dry and hard for most other legumes.

Bur clover makes its growth in winter and spring and does well on soils which are quite sandy, and even those which contain little lime. It begins its growth in the fall, soon after the Bermuda grass has been cut by frosts, and ripens its seed and disappears at about the time the grass begins its growth in the spring, so it is practically an alternating crop. It makes excellent grazing for hogs and calves, but is of less value for grown cattle and is not eaten readily by mules and horses until after the seed begins to ripen. A combination of bur clover and Bermuda grass is one of the best successions for a permanent pasture for hogs and calves, as it furnishes good grazing throughout most or all of the year.

Black medic has proved of decided value for growing with Bermuda grass in northern Alabama, Mississippi, and Louisiana, and its use is being rapidly extended to other sections. Its growth is not as rank as that of bur clover, but it gives grazing both earlier and later in the season and is eaten more readily by cattle and mules. It grows larger on clayey than on sandy soils and is better adapted to the hardwood region than to that of the piny woods.

These three legumes are all annuals, but reseed the ground freely and so need be planted in pastures but once.

Melilotus usually does not bloom until the second season, but in every field there will be a few plants which produce seeds the first year. Many of the seeds of the original sowing do not germinate until the second season, so the crop is practically continuous and needs to be planted but once. Melilotus grows taller and coarser than the other legumes mentioned, but will thrive on soils too thin and barren for the others, provided it is rich in lime. If lime is plentiful it will grow well on very thin and barren spots where the Bermuda grass will make only a weak growth. It has an unusually large and powerful taproot, and after having been grown on a hard soil a few years causes the soil to become so mellowed and so enriched by the nitrogen and humus left by the decay of the roots that the land is more easily cultivated and more productive. As the soil is brought into a better condition the melilotus gradually disappears and is replaced by a growth of Bermuda grass.

All of these legumes have taproots, which by their quick decay at the end of the season make the soil less compact and by their humus-making and nitrogen-gathering work serve to increase its fertility. At the same time their growth prevents the Bermuda grass from becoming sod bound and so tends to increase the yield of this grass.

Lespedeza and at least one of the other legumes mentioned should be planted in every Bermuda-grass pasture.

BERMUDA GRASS FOR HAY.

The yield of Bermuda grass for hay, as well as for pasture, varies greatly with soil and location. On dry, clay hills at the Mississippi Agricultural Experiment Station, when fertilized with 10 tons of stable manure per acre it has yielded at the rate of 2½ tons per acre. On the black prairie lands of eastern Mississippi and Alabama it yields 1 to 1½ tons per acre at each of two cuttings, while on the rich alluvial lands along the Mississippi and Red Rivers it gives 2 to 3 tons per acre at each of two or three cuttings. The Report of the Oklahoma Agricultural Experiment Station for 1907 records a yield of 11,704 pounds of dry hay per acre, and Prof. J. S. Newman, in Bulletin No. 76 of the South Carolina Agricultural Experiment Station, reports 13,000 pounds of dry hay per acre. In the South Carolina Report for 1888 Dr. St. J. Ravenel mentions a yield of 10 tons per acre. Other growers report equally good or even heavier yields.

In the southern and western parts of its territory and on the immediate Gulf coast, Bermuda grass seldom grows large enough to be profitable for hay, but in the central part of the Southern States it is a valuable and reliable hay plant on all rich and fairly moist soils.

Both meadows and pastures are likely to become somewhat sod bound after having been in Bermuda grass a few years. In pastures this may be almost wholly prevented by planting lespedeza, bur clover, melilotus, or some other legume.

Legumes, however, are less practicable in meadows, and there the sod must be broken up by plowing or disking. Some growers use an ordinary mole subsoil plow for this purpose, running the plow 3 to 4 inches deep and making the furrows about a foot apart. This is very satisfactory, as it loosens the soil and still leaves the surface smooth. A heavy disking will accomplish the same purpose, but should be followed by a smoothing harrow or a heavy roller to smooth the surface.

As long as a meadow or a pasture is giving a satisfactory yield it should not be disturbed.

BERMUDA GRASS FOR TURF.

Bermuda grass makes an excellent sod for lawns and golf grounds, as it forms an even turf without clumps or coarse stems. It is easily kept clipped with a lawn mower, and as it recovers quickly it gives a smooth and even surface. The greatest objection to it for the purpose is that it becomes browned after the first severe frost and so is not attractive in appearance during the winter. That, however, can be easily overcome by seeding the lawn with Italian rye-grass in the early fall. This grass comes up very quickly, bears clipping

well, is not injured by frosts, and so keeps the lawn green through the winter. It dies and disappears in the spring at about the time Bermuda grass starts into growth. By using such a mixture it is not difficult to keep the lawn in good condition through the entire year.

White clover may be used in the same way, and as it is a perennial it need be seeded but once. It will add greatly to the freshness of a lawn during the winter and will also improve the growth of the Bermuda grass during the summer.

The character of growth in Bermuda grass varies with its treatment. When kept clipped or grazed closely and trampled heavily the stems become slender, prostrate, and spreading, with numerous short leaves; but when neglected the plants become much coarser, the stems more nearly erect, and the leaves much longer and broader. A good lawn can be made only with constant care.

When Bermuda grass is used for a lawn it is desirable to fertilize liberally with cottonseed meal or ground bone and to water freely. When the grass is used for the putting greens on golf grounds, however, very little fertilizer or water should be applied, since the grass makes a shorter and more satisfactory growth under such treatment.

BERMUDA GRASS FOR SOIL BINDING.

In nearly all the South erosion, or the washing out of gullies on cultivated and hilly lands, is a serious matter, and Bermuda grass is the best plant which has been found to check the damage from this cause. When planted in newly formed or even in old and large gullies it catches the washed-down soil, holds it in place, and soon makes such a growth that the spread of the gully is stopped and at length filled, so that it becomes cultivable ground again. The planting of the grass in newly formed gullies will soon smooth them off. There is no excuse for the formation of destructive and wasteful gullies in any region where Bermuda grass can be grown.

Almost the entire course of the Mississippi River from Cairo southward to the Gulf of Mexico is protected from overflows by a series of levees which have been built with soil from the adjacent lands. These levees must be protected from washing, and Bermuda grass is universally used for the purpose, as its matted rootstocks bind the soil and prevent washing better than any other grass. For this purpose the ordinary variety, producing numerous underground rootstocks, is better than those producing only surface runners.

MARKET VALUE.

The market value of Bermuda hay, like that of all other hays, depends largely on its condition and appearance when offered for sale. The brighter its color and the better the appearance of the bales, the higher the price it will bring.

No detail in the marketing of hay has more to do with the final profit than the matter of grading. If a customer wants a fancy grade of hay, he must be willing to pay a fancy price, while if he is willing to accept a grade which is less fancy but which is just as good for feeding purposes, he usually will be able to purchase his supply at a much lower price.

The National Hay Association standard grades for different hays are now generally used in all leading hay markets. These grades for Bermuda hay are as follows:

No. 1. Bermuda hay shall be Bermuda grass mixed with not more than 10 per cent of native grasses, color of uniform greenish cast, sound, tender, and well baled.

No. 2. Bermuda hay shall be Bermuda grass mixed with not more than one-fourth native grasses, color of greenish cast, with not more than 15 per cent brownish blades, sound, tender, and well baled.

No. 3. Bermuda hay shall be Bermuda grass mixed with not more than one-fourth native grass, color of brownish cast, sound, and well baled.

While there are no great differences in the actual feeding values of the three grades, there is a considerable difference in their market selling prices, and the grower should govern his practice accordingly.

Hay which has a bright-green color is always in demand, as it has been well cured. As a matter of fact, as has been shown by many tests in this country and in Europe, hay which has become somewhat browned in curing but which is not moldy or musty is just as valuable for feeding as that which is green in color, but it does not sell as well on the market. In the United States green hay commands a much higher price. The grower should always try to make green hay when he proposes to sell the product, while the browned hay can be saved for use on the farm. Horses and mules will eat the latter hay as readily as the former. The greatest value in the green color is as a guaranty that the hay is well cured and free from dust and mold.

The next most important specification is in regard to baling. All grades must be well baled, as no customer wants bales with one or two loose wires.

FEEDING VALUE.

Little accurate work has been done at any of the agricultural experiment stations in making either feeding or digestion tests with Bermuda hay, though the general experience of feeders in all parts of the South has shown that it is fully as valuable as any other grass hay.

Bulletin No. 15 of the Mississippi Agricultural Experiment Station reports that six lots of cows, five cows in each lot, were fed for testing different rations for the production of milk and butter. One of these lots was fed with Bermuda grass and another with timothy hay, both lots receiving the same grain ration. The financial results of

the test were based on Bermuda hay at $12.50 a ton and timothy at $20.80, the actual cost at the time. On that basis the cost of the milk from the Bermuda-fed lot was 7.7 cents a gallon and of the butter 17.4 cents a pound, while the milk from the timothy-fed lot cost 12.8 cents a gallon and the butter 29.5 cents a pound. The bulletin says: "Had the timothy cost no more than the Bermuda hay the cost would have been 9.5 cents a gallon for the milk and 21.9 cents for the butter." This leaves a margin of about 25 per cent in favor of the Bermuda hay.

This work was continued the following year and the results, as given in Bulletin No. 21, were slightly less favorable to Bermuda-grass hay but indicated that "ton for ton the two hays have practically the same milk and butter producing values" and "at the prices at which they can be purchased in Mississippi, Bermuda hay will produce milk or butter at a much less cost than will timothy."

Bulletin No. 15 of the Mississippi Agricultural Experiment Station, in reporting on the values of different hays for mules, says:

> In order to ascertain the comparative values of Bermuda and timothy hays for feeding to working animals, the six working mules belonging to the station were divided into two lots, one mule from each double team being placed in each lot. Both lots received the same amount of corn daily and were given all the hay they could eat, the feeding being continued two months. The results showed that there was practically no difference between the two rations, the food for the lot fed with timothy costing 36 cents more for the entire period than that for the Bermuda-fed lot, the lot receiving timothy gaining 92 pounds during the two months, while the other lot gained 90 pounds.

Prof. E. R. Lloyd, director of the Mississippi Agricultural Experiment Station, in a recent letter published in the Progressive Farmer, states that another test was made in 1915 with five lots of mules, each lot containing four or five 2 and 3 year old mules, the test being continued 89 days. Each lot received the same amount of grain per mule but were fed with different hays. Bermuda grass, Johnson grass, timothy, lespedeza, and alfalfa hays were used and the cost of each was figured at the local market price then prevailing. The cost of feed for each lot for the 89 days was as follows:

Bermuda grass	$14.36
Johnson grass	14.36
Lespedeza	16.38
Alfalfa	16.38
Timothy	18.90

The feeding value of any hay is indicated to some extent by a chemical analysis showing the proportions of its several nutritive components, and of these components the protein is by far the most important. These components in Bermuda grass, timothy, and Kentucky bluegrass, as given by the Bureau of Chemistry of the Department of Agriculture, are shown in Table I. The calculations were made on a water-free basis.

TABLE I.—*Chemical analyses of Bermuda grass, timothy, and Kentucky bluegrass.*

Crop.	Number of samples.	Protein.	Fiber.	Starch, etc.	Fat.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Bermuda grass	19	10.50	27.48	51.18	2.54
Timothy	194	8.19	32.53	49.87	3.18
Kentucky bluegrass	84	11.89	29.48	47.37	3.57

From the above it will be seen that Bermuda grass contains 2.31 per cent more protein than timothy and 1.39 per cent less than bluegrass, as well as more starch and less fiber than either.

In American literature only a single digestion test with Bermuda hay is recorded, so there is need for further work along this line to determine its feeding value more definitely. A comparison of the digestibility of Bermuda hay, as shown by Bulletin No. 90 of the Oklahoma Agricultural Experiment Station, giving the results of tests with sheep, and the digestibility of timothy and bluegrass, as shown by various publications of the Department of Agriculture and several of the agricultural experiment stations, is given in Table II.

TABLE II.—*Comparative digestibility of Bermuda grass, timothy, and Kentucky bluegrass.*

Crop.	Protein.	Fiber.	Nitrogen-free extract.	Fat.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Bermuda grass [1]	64.2	58.9	52.7	39.6
Timothy	48	50	62	50
Kentucky bluegrass	57	66	61	52

[1] The analysis of the hay used in the work of the Oklahoma Agricultural Experiment Station was as follows (per cent): Water, 7.87; ash, 7.44; protein, 10.81; fiber, 28.87; nitrogen-free extract, starch, etc., 43.58; fat, 1.42.

While these figures indicate the possible feeding value of Bermuda grass, its actual value can be determined only by repeated feeding tests with different animals. In making such tests the feeder must take into consideration the soil on which the grass was grown, the character of the season, and the age at which the grass was cut, as each of these conditions will influence both the composition and the digestibility of the hay.

Timothy was one of the first hay grasses to be grown in this country and by its wide cultivation and extensive use has become the standard by which other grass hays are judged. For this reason many buyers suppose timothy to be the best in quality. Southern feeders, however, are beginning to recognize the value of Bermuda grass. In all the regions where this grass can be grown well a dollar's worth of it will furnish more feed than a dollar's worth of timothy. It is therefore the cheaper hay for use in the South.

Furthermore, at present prices, on the farms where grown, Bermuda grass is more profitable to the southern farmer than timothy is to the northern grower.

ERADICATION.

Many farmers hesitate to plant Bermuda grass for fear it can not be killed out when the land is wanted for other purposes. It may be thoroughly eradicated, however, when advantage is taken of its peculiarities. It is almost impossible to kill Bermuda grass by cultivation in the summer or by deep plowing at any season. In the northern part of the Bermuda-grass region it can be almost or wholly eradicated by a very shallow plowing late in the fall, leaving the furrows on edge as much as possible, so that the "roots" will be frozen during the winter. Few of the "roots" will survive a single heavy freeze when turned up and exposed to the air. Farther south, where frosts are less severe the grass must be killed by smothering. Bermuda grass will bear almost unlimited heat, drought, and sunshine, but it can not live when shaded. When it is desirable to clear a field it should be plowed in September and planted with oats, rye, barley, or some other winter crop. When that crop is harvested the ground should be disked or plowed at once and then planted with cowpeas or velvet beans. When the pea or bean crop is removed, there will be little or no Bermuda grass left. This gives two profitable crops during the year and leaves the ground in prime condition for corn or cotton the following season.

Another method, which is often followed, is to plow the sod very shallow in the fall, harrow thoroughly, and then rake the "roots" into windrows and haul them off. If this process is repeated in the spring little of the grass will be left. A bulletin of the South Carolina Agricultural Experiment Station says that the grass may be killed by disking, cross disking, and harrowing a few times during the winter.

In California and other arid regions it can be killed by withholding irrigation a few months. Varieties like the Giant and the St. Lucie, which have no underground rootstocks, can be almost wholly killed by allowing the late fall growth to stand and then burning it off after it has become dry. It is much more easily killed on light than on heavy soils.

SUMMARY.

Bermuda grass is the most valuable perennial grass in the southeastern part of the United States and is common in all the warmer parts of the world. It has been grown in the United States for more than a hundred years.

It requires a warm climate for its best growth; it does not bear heavy freezing or dense shading, but endures drought better than most other grasses. It grows best on a soil which is fertile, fairly moist, well drained, and rich in humus and nitrogen.

There are several distinct varieties, differing principally in vigor of growth and in the character of the rootstocks and runners. Of the many forms which have been tested by the United States Department of Agriculture the Giant grows most rankly and so is the best for hay.

The yield of hay varies greatly with the locality in which it is grown. In many localities Bermuda grass does not grow large enough to pay for cutting, while on very favorable soils it may yield annually 6 to 8 tons of hay per acre.

It is the best permanent pasture grass in most of the South. On soils of ordinary fertility it will support about 1 steer per acre for eight to nine months, while on exceptionally favorable soils it may support four or five steers for a longer time. Pastures may be greatly improved by growing some legume with the Bermuda grass—lespedeza, bur clover, black medic, and melilotus being the species commonly used for the purpose.

Bermuda grass is of great value for use in stopping the washing of gullies and in binding levees and other embankments.

Its feeding value is fully equal to that of timothy, though its market value is usually less.

It can be eradicated either by freezing the "roots" or by keeping the ground heavily shaded by the growing of other crops.

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FARMERS' BULLETIN 813

CONSTRUCTION AND USE OF FARM WEIRS

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UNITED STATES
DEPARTMENT OF AGRICULTURE

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CONSTRUCTION AND USE OF FARM WEIRS.

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NEED OF FARM WEIRS.

In the arid west vast sums of money have been expended in the construction of ditch and canal systems to carry water to the lands where the rainfall is either insufficient or too uncertain for profitable agriculture, and the farmers have spent a still greater amount for preparing the land for irrigation and for purchasing "water rights," which entitle them to a certain amount of water. The value of the water has increased with the development of the country and now there is a general demand that the water be measured from the ditch to the irrigator as well as from the stream to the main canal. This is an important step toward better business methods in the management of canal systems and farms, and calls for accurate and reliable information concerning devices suited to the measurement of comparatively small streams of flowing water.

DEFINITIONS.

The "weir" is one of the most commonly used devices for this purpose. A bulkhead or wall built across a ditch or stream, with an opening cut in the top of the wall through which the water is allowed to pass, is called a "weir" and the opening is called the "weir notch." The bottom portion of the ditch immediately upstream from the bulkhead is the "weir box" or "weir pond." The height of the water surface in the weir pond above the weir crest is the "head." When the water flows over the crest into the air before it strikes the surface of the water in the ditch downstream from the bulkhead, it is said to have "free fall," and when this overpouring stream of water touches only the sharp upstream edge of the crest, the weir is

NOTE.—The work on which this bulletin is based was done in the hydraulic laboratory at Fort Collins, Colo., under a cooperative agreement between the Office of Experiment Stations, United States Department of Agriculture, and the Colorado Agricultural Experiment Station.

For a technical report on the experimental data see Journal of Agricultural Research, Vol. V, No. 23, March 6, 1916.

The purpose of this bulletin is to give practical directions for the construction and use of the smaller sizes of weirs, such as are suited to the measurement of water on irrigated farms.

said to be "sharp crested." The weir notch must have a definite shape and size. The horizontal distance from the end of the weir crest to the side of the weir box is called "end contraction," and the vertical distance from the crest to the floor of the weir box is called "bottom contraction." When these contraction distances are great enough to cause a pondlike condition, which permits the water to approach the weir notch without any appreciable velocity, the weir is said to have "complete contractions."

The weirs described in this bulletin are the rectangular, Cipolletti, and 90° triangular-notch types, with free fall, sharp crests, and complete contractions. The discharge formulas for these weirs are not confined to the limits imposed upon old formulas. They are correct for high as well as low heads, at least within the range given in the tables.[1] However, in order to lessen the cost for materials for constructing the weirs, the dimensions of the weir boxes, as given in Table 1, are less than required for complete constructions, and therefore the discharges over these weirs will be greater than represented by the formula or discharge tables. The excess reaches a maximum of only about 1 per cent for the higher heads, and consequently can be ignored for practical conditions.

To determine the quantity of water flowing at any time, read the gauge, which gives the "head" or depth of water flowing over the weir notch, and turn to the discharge table in this bulletin for the type of weir used. If the head is measured in feet and decimals, find it in the first column, or if measured in feet and inches, find it in the second column, and following along this line to the right, find the number in the column for the length of weir crest used. This number will be the flow in cubic feet per second, which may be changed into miner's inches—or statute inches—by multiplying by the number of miner's inches equal to a cubic foot per second, as given in the table of hydraulic equivalents on the last page of this bulletin.

ADVANTAGES AND DISADVANTAGES OF WEIRS WITH COMPLETE CONTRACTIONS.

The principal advantages and disadvantages of the types of weirs described herein may be stated as follows:

Advantages.—They are (1) accurate; (2) they are simple and may be constructed by the farmer; (3) they permit moss and floating trash to pass through the ditch without great danger of interfering with the measurement of the water; and (4) they are durable and require no adjustment for proper operation, for there are no working parts.

[1] A full discussion of the experiments upon which these formulas are based is contained in Journal of Agricultural Research, vol. 5, No. 23, Mar. 6, 1916.

Disadvantages.—(1) They require a considerable pondage above the weir; (2) they can not be used where there is only a slight grade to the ditch; (3) they are not adapted to ditches that carry much sand and silt; and (4) practically all undesirable conditions, such as accumulation of sand and silt above the weir, water approaching the weir with velocity, or injury to the weir crest, tend to give a greater flow of water than that indicated in the tables.

WEIR BOX AND WEIR POND.

When properly constructed either of the three types of weirs described herein is reliable and accurate for the measurement of flowing water. They may be placed in any ditch or canal having sufficient fall, but it is necessary that the ditch be made wider and deeper for some distance upstream from the weir notch. This enlargement is for the purpose of making practically a still-water condition before water flows over the weir. The weir box or weir pond, which is immediately upstream from the weir notch, has a uniform length, width, and depth as given in Table 1, and commencing at approximately 50 feet upstream from the weir the ditch must be enlarged gradually from the regular size of the ditch to the full size of the weir box. The length of this tapering enlargement, stated as 50 feet, really needs to be greater or less as the flow in the ditch is large or small as compared to the size of the weir notch, and it will depend also upon the size of the ditch and the velocity of the water in the ditch.

Where the available grade in the ditch is not great enough to give the required depth of pond by raising the banks for a distance of 50 to 100 feet back from the weir, the bottom may be lowered and the banks raised only enough to give a free fall below the weir notch. However, the weir pond, whether a box or an enlargement of the ditch, must not be allowed to fill with silt and sediment or other débris. The water must approach the weir in straight lines without swirling or eddy currents.

A weir box may be built as shown in figure 1, or a bulkhead may be placed in an enlargement in the ditch as shown in figure 2. This latter arrangement will permit cleaning of the pond with teams and scrapers, and is easy and inexpensive to construct, but because of the sloping banks, the water surface must be wider than where a box is built with vertical sides. The bottom of the ditch for a short distance downstream from the weir should be lined with rock to prevent scouring due to the water falling over the weir notch. Where a complete weir box is built of timber or concrete it looks well, occupies the least land area and has greater permanency, but it is more costly and more difficult to clean. A floor or apron, as given in column K in Table 1, constructed of the same material as the weir box, over-

comes the necessity for lining the ditch with rock below the weir. Precautions should be taken to prevent water from washing under the bottom or around the sides of the box. For most soils, if the earth is puddled with water as it is filled around the box, it will be safe; but where it is sandy or likely to wash, a board 12 inches wide should be placed on edge under the bottom and at the sides near the upper end of the box, to serve as a cut-off wall. The height of the weir crest above the bottom of the ditch downstream from the weir notch will depend upon the size and grade of the ditch, but this height must be such that when the greatest quantity of water is flowing over the weir the water level in the ditch downstream will be below the crest. This is to permit the free passage of air between the bulkhead and the sheet of over-pouring water, which is the required condition for free flow.

Table 1 gives the sizes of weirs best adapted to measuring flows of water varying from one-half to 22 cubic feet per second, and the proper dimensions for each size of rectangular, Cipolletti, and 90° triangular notch weirs.

TABLE 1.—*Weir-box dimensions for rectangular, Cipolletti, and 90° triangular-notch weirs.*

[All dimensions in feet. The letters at the heads of the columns in this table refer to figure 1.]

RECTANGULAR AND CIPOLLETTI WEIRS.

Flow (second-feet).	H. Maximum head.	L. Length of weir crest.	A. Length of box above weir notch.	K. Length of box below weir notch.	B. Total width of box.	E.[1] Total depth of box.	C. End of crest to side.	D. Crest to bottom.	F.[2] Hook-gage distance.	G.[3] Hook-gage distance.
½ to 3	1.0	1	6	2	5½	3½	2½	2	4	2
2 to 5	1.1	1½	7	3	7	4	2½	2½	4½	2
4 to 8	1.2	2	8	4	8½	4½	3	2½	5	2½
6 to 14	1.3	3	9	5	12	5	4½	3½	5½	3
10 to 22	1.5	4	10	6	14	5½	5	3½	6	3
90° TRIANGULAR NOTCH WEIR.										
½ to 2½	1.00	.....	6	2	5	3	2½	1½	4	2
2 to 4½	1.25	.....	6½	8½	6½	3½	3½	1½	5	2½

[1] This distance allows for about ½ foot freeboard above highest water level in weir box.
[2] Equals distance from crest upstream to gauge.
[3] Equals distance from end of crest over to gauge.

As previously stated, using the weir boxes specified in Table 1 will give results within 1 per cent of correct. If smaller boxes are used the actual discharges will be larger than those given in the tables.

Tables 2 and 3 show the percentage increase in discharge caused by weir boxes smaller than required for complete contractions, for rectangular and Cipolletti weirs having crest lengths from 1 to 4 feet, and with heads of six-tenths and 1 foot.

If the smaller boxes are used, discharges should be read from the tables and increased by the percentages given in Tables 2 and 3.

TABLE 2.—*Velocity of approach and percentage of error caused by different end and bottom contractions*

TABLE 2.—*Velocity of approach and percentage of error caused by different end and bottom contractions for rectangular weirs.*

B. Distance of bottom below crest.	A. Distance of sides from end of crest.	Length 1 foot.				Length 1.5 feet.				Length 2 feet.				Length 3 feet.				Length 4 feet.			
		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.	
		Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.
Feet.	*Feet.*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
3.0	2.5			0.132	0.77																
3.0	2.0			.157	.81			0.213	0.82			0.269	0.84			0.342	0.83			0.402	0.87
3.0	1.5			.196	.099			.260	1.08			.317	1.14			.399	1.22			.460	1.29
3.0	1.0			.260	1.40			.337	1.63			.398	1.81			.484	2.06			.543	2.22
3.0	.5			.40	2.94			.477	3.22			.540	3.44			.616	3.72			.661	3.88
2.5	2.5			.150	.74																
2.5	2.0			.178	.82			.242	.88			.302	.94			.391	1.04			.460	1.11
2.5	1.5			.224	1.05			.297	1.21			.362	1.34			.461	1.57			.528	1.69
2.5	1.0			.299	1.58			.385	1.89			.457	2.14			.553	2.50			.623	2.76
2.5	.5			.462	3.42			.549	3.73			.625	3.99			.704	4.25			.760	4.48
2.0	2.5	0.94	0.17	.175	.73																
2.0	2.0	.115	.26	.209	.84			.284	.97			.352	1.11			.458	1.30			.539	1.42
2.0	1.5	.148	.39	.261	1.13			.348	1.42			.424	1.67			.538	2.01			.620	2.28
2.0	1.0	.188	.66	.353	1.83			.450	2.28			.535	2.63			.648	3.14			.733	3.52
2.0	.5	.288	2.05	.538	4.01			.646	4.46			.728	4.80			.829	5.17			.895	5.47
1.5	2.5	.119	.17	.208	.74																
1.5	2.0	.141	.30	.252	.94	1.91	0.53	.341	1.18	0.239	0.74	.424	1.41	0.308	1.07	.539	1.71	0.365	1.33	.638	1.98
1.5	1.5	.175	.40	.314	1.31	.234	.73	.418	1.74	.286	1.01	.512	2.12	.363	1.44	.648	2.65	.416	1.74	.750	3.07
1.5	1.0	.234	.76	.424	2.24	.304	1.24	.544	2.87	.361	1.62	.646	3.40	.435	2.12	.790	4.14	.489	2.49	.889	4.68
1.5	.5	.355	2.26	.648	4.80			.784	5.53			.885	6.09	.552	3.41	1.013	6.77			1.091	7.20
1.0	2.5	.154	.19	.260	.82																
1.0	2.0	.209	.36	.314	1.12			.427	1.57			.532	2.00			.694	2.69			.810	3.15
1.0	1.5	.229	.50	.385	1.59	.311	1.09	.528	2.37	.377	1.55	.645	2.99	.478	2.25	.820	3.91	.552	2.79	.952	4.60
1.0	1.0	.308	1.01	.525	2.83	.400	1.77	.688	3.86	.476	2.39	.825	4.73	.577	3.22	.999	5.87	.650	3.83	1.135	6.77
1.0	.5	.469	2.84	.822	6.00	.573	3.74	.994	7.29	.646	4.38	1.129	8.29	.735	5.15	1.298	9.55	.794	5.64	1.305	10.27
.5	2.5	.221	.25	.350	1.11																
.5	2.0	.265	.50	.417	1.45	.368	1.30	.575	2.40	.460	2.05	.720	3.27	.624	3.34	.943	4.62	.711	4.05	1.120	5.65
.5	1.5	.337	.94	.530	2.20	.453	1.94	.710	3.53	.555	2.84	.875	4.73	.705	4.17	1.119	6.50	.818	5.15	1.308	7.88
.5	1.0	.450	1.84	.716	3.83	.588	3.22	.930	5.65	.704	4.35	1.118	7.23	.862	5.92	1.380	9.40	.975	7.01	1.576	11.2
.5	.5	.695	4.63	1.120	8.25	.852	6.43	1.37	11.0	.970	7.79	1.58	13.3	1.112	9.40	1.83	16.01	1.208	10.50	2.01	18.0

TABLE 3.—*Velocity of approach and percentage of error caused by different end and bottom contractions for Cipolletti weirs.*

B. Distance of bottom below crest.	A. Distance of sides from end of crest.	Length 1 foot.				Length 1.5 feet.				Length 2 feet.				Length 3 feet.				Length 4 feet.			
		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.		Head 0.6 foot.		Head 1 foot.	
		Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.	Velocity of approach.	Percent of error.
Feet.	*Feet.*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
2.0	2.0	.....	.....	0.250	1.19	.....	.....	0.322	1.22	.....	.....	0.386	1.24	.....	.....	0.488	1.28	.....	.....	0.561	1.30
2.0	1.5	.....	.....	.314	1.52	.....	.....	.397	1.70	.....	.....	.467	1.84	.....	.....	.575	2.08	.....	.....	.648	2.22
2.0	1.0	.....	.....	.422	2.40	.....	.....	.514	2.80	.....	.....	.590	3.15	.....	.....	.698	3.62	.....	.....	.769	3.92
2.0	.5	.....	.....	.655	6.16	.....	.....	.746	6.41	.....	.....	.813	6.61	.....	.....	.896	6.88	.....	.....	.951	7.01
1.5	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.5	2.0	0.158	0.84	.300	1.34	0.207	1.02	.388	1.49	0.251	1.21	.465	1.61	0.321	1.45	.590	1.82	0.373	1.61	.680	1.98
1.5	1.5	.196	1.11	.378	1.78	.255	1.38	.477	2.10	.304	1.60	.562	2.40	.377	1.95	.693	2.85	.429	2.19	.785	3.17
1.5	1.0	.260	1.70	.508	2.89	.329	2.08	.622	3.53	.381	2.36	.714	4.06	.454	2.77	.844	4.79	.504	3.02	.937	5.31
1.5	.5	.400	3.32	.795	7.29	.469	3.83	.906	7.79	.518	4.20	.989	8.18	.580	4.66	1.094	8.64	.617	4.93	1.163	8.85
1.0	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.0	2.0	.205	.09	.374	1.60	.274	1.25	.489	2.06	.331	1.55	.586	2.44	.425	2.05	.758	3.13	.492	2.39	.864	3.55
1.0	1.5	.257	1.20	.471	2.20	.335	1.71	.601	2.92	.400	1.55	.710	3.55	.500	2.82	.888	4.53	.569	3.30	1.003	5.19
1.0	1.0	.344	1.84	.643	3.76	.434	2.60	.787	4.83	.501	3.17	.908	5.73	.607	4.06	1.083	7.07	.671	4.60	1.200	7.92
1.0	.5	.529	4.00	1.010	9.20	.622	4.92	1.159	10.28	.690	5.61	1.271	11.08	.770	6.41	1.410	12.09	.826	6.98	1.503	12.72
.5	2.5	.....	.....	.64	3.3	.....	.....	.818	4.8	.....	.....	.968	6.07	.....	.....	1.21	8.07	.....	.....	1.391	9.56
.5	2.0	.300	1.11	.508	2.30	.399	1.81	.660	3.64	.487	2.42	.799	4.87	.625	3.40	1.013	6.73	.725	4.09	1.202	8.39
.5	1.5	.377	1.51	.640	3.30	.492	2.55	.818	4.80	.589	3.44	.969	6.09	.737	4.79	1.210	8.08	.847	5.80	1.391	9.56
.5	1.0	.505	2.39	.864	5.40	.636	3.93	1.077	7.58	.750	5.30	1.258	9.43	.908	7.18	1.505	11.95	1.013	8.39	1.688	1.38
.5	.5	.782	6.03	1.390	11.89	.932	8.02	1.605	14.63	1.037	9.43	1.782	16.85	1.173	11.28	2.015	19.80	1.263	12.48	.....	.....

WEIR CRESTS AND SIDES.

Weir crests and sides should be true, straight, and rigid. The crest must be level, the sides must be set to the proper angle with the crest, and carefully spaced to give the correct length of crest, as indicated by "L" in figure 1 and Table 1. The 90° triangular notch has no length of crest because the sides meet at a point.

It is not necessary that the sides and crest be sharpened to a knife edge, but the edge of the crest on the upstream side must be sharp in the sense that it is not rounded. If a depth of water not less than 3 inches is to be run over the weir, the crest thickness on the edge may be as great as one-fourth inch without the water adhering to the crest, provided the inner edge is sharp. However, if the crest is beveled, this bevel must be placed on the downstream side, for the upstream face of the crest and of the bulkhead which holds the crest must be even and in a vertical position. The downstream face of the opening in the bulkhead must be beveled outward and downward about 45 degrees to insure free passage of air under the sheet of water as it flows over the weir.

Instead of cutting the notch in the bulkhead to just the size desired and leaving this rather rough edge to serve as the crest and sides of the weir notch, it is better to make the opening in the bulkhead at least 1 inch deeper and 2 inches wider than the desired size of weir opening. This will permit attachment of crest and side strips to the bulkhead so as to project about an inch all around, making more perfect edges, and the overpouring sheet of water will not touch the bulkhead.

Wood may be used for the crest and sides, but as it is apt to warp, wear, and become splintered, metal is preferable. For the smaller sizes of weirs, the proper weir opening may be cut out of a single sheet of metal which may be fastened to the bulkhead. For the larger weirs crests and sides made from separate strips of metal having the edges filed true are more practical. This metal should be fairly heavy, to prevent the strips from bending and getting out of alignment easily. A more durable crest may be made of 1½-inch angle iron cut to the required lengths and set into the bottom and sides of the opening cut in the bulkhead. One face of the angle iron will be flush with the upstream side of the bulkhead and the other face will be fastened securely into the opening in the bulkhead. The edge over which the water will pass therefore will project 1½ inches from the opening in the bulkhead, and should be made true with squared edge.

If strips of wood are used for the crest and sides, they usually are fastened to the upstream face of the bulkhead for convenience, but in this case these strips must not be narrow, as this would give a pro-

jection the thickness of the strip, which will reduce the accuracy of the measurement of the water. With whatever type used, the joints formed by the sides and crest must fit nicely without leaving a crack and without causing an offset.

WEIR GAUGE.

The weir gauge, which is used to measure the depth of water flowing over the weir crest, may be an ordinary "ruler" or a hardwood stick graduated to feet and inches, but it is preferable to have it graduated to feet, tenths and hundredths of a foot. It should be set upstream from the weir notch a distance ("F" in fig. 1 and Table 1) at least four times the maximum depth of water ("H") to be run over the crest, or, if placed on the weir bulkhead, the distance "C," measured out from the end of the weir crest, should be at least two times the depth "H." If a complete weir box has been built, the gauge may be fastened to the bulkhead or the side of the box, as indicated in figure 1. If, instead of a weir box, an enlargement has been made in the ditch above the bulkhead, the gauge may be attached to a solid post set just far enough from the bank to insure that it always will be in the water. If a perma-

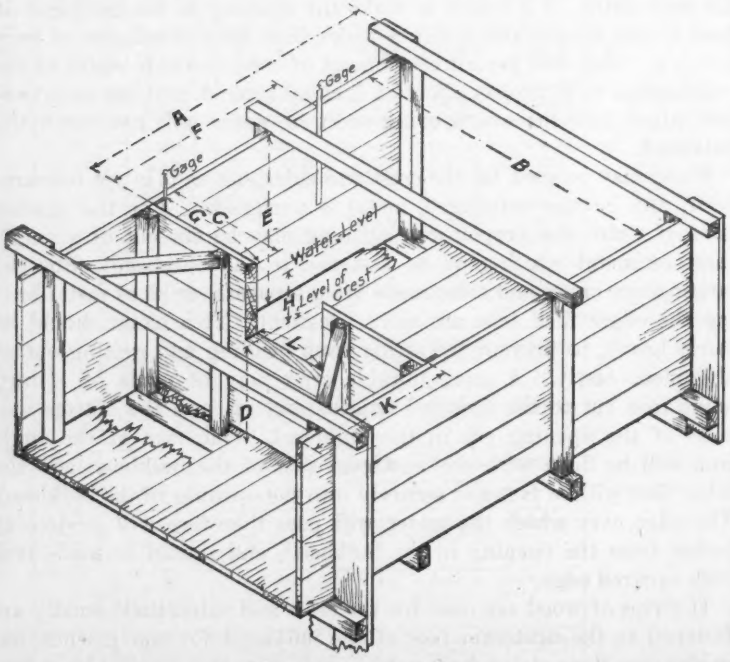

FIG. 1.—Plan of weir box.

nent gauge is not desired, a block or other solid support should be provided at the proper distance upon which to set a scale when taking readings.

The reason for placing the gauge as described is that the depth of water "H," from which the flow over weirs is computed, is measured vertically from the weir crest to the horizontal plane of the still-water surface in the weir pond upstream from the weir. There is a decided curving downward of the water surface near the weir notch, and it is necessary to get beyond the effect of this curvature, called "draw down," in order to get the correct depth of water "H."

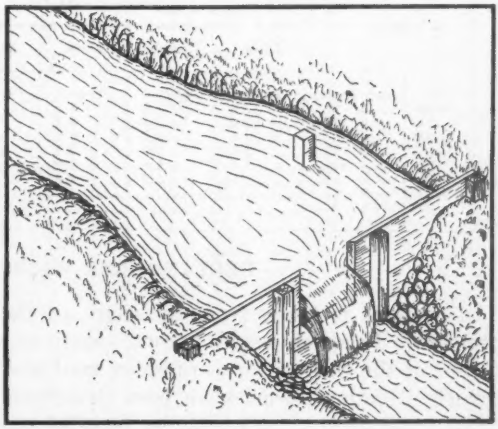

FIG. 2.—Weir notch and bulkhead in weir pond.

The zero of the gauge should be set level with the weir crest for rectangular and Cipolletti weirs, and with the lowest point in the 90° triangular notch, which has no real crest; but this level should not be determined by allowing the water to start to flow over the weir crest and marking the zero of the gauge from that water level, for, in fact, the water level must be appreciably higher than the crest before it will pour over the weir. It would be better to set the gauge with a good carpenter's level. Furthermore, before the beginning of each irrigation system, or oftener, the position of the weir crest and sides and the gauge should be checked carefully, for frost action or settlement in the wet soil may have altered their original position.

Where a hook gauge or an automatic recording gauge is to be used in connection with the weir, a water-tight still-box or gauge well should be provided outside of the weir box and connected to the weir box by means of a pipe laid through the bank below the level of the weir crest. The still-box should be placed upstream from the weir notch, a distance at least as great as shown in column "F" in Table 1, and should be enough deeper than the pipe to prevent silt accumulation from stopping the free passage of water through the pipe. It should be cleaned occasionally. The purpose of the box is to provide a still-water surface at the same level as the water in the weir box.

In order to obtain a correct measurement of the water flowing over a weir it is very necessary that the depth of water "H" be determined accurately. This means that the gauge must be placed accurately and read carefully. To show the error caused by misreading the gauge 0.01 foot, or slightly less than one-eighth inch, Table 4 is given.

TABLE 4.—*Percentage of error in discharge caused by 0.01 foot error in reading the head.*

Head.			Length of weir crest.					90° notch.
			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.	
Feet.	*Feet.*	*Inches.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.20	0	2½	7.2	7.5	7.5	7.6	7.6	.....
.30	0	3⅝	5.0	5.1	5.1	5.6	4.8	8.5
.50	0	6	3.5	3.2	3.0	2.9	2.9	5.0
.70	0	8⅜	2.1	1.9	2.1	2.2	2.2	3.9
.90	0	10⅞	1.8	1.8	1.8	1.7	1.7	2.9
1.10	1	1⅓	.....	1.4	1.3	1.3	1.3	2.2
1.25	1	3	.....	.....	.....	1.1	1.1	2.1
1.50	1	6	.....	.....	.....	0.9	1.0	.....

RECTANGULAR WEIRS.

The name is taken from the shape of the weir notch, shown in figure 3. This weir is also known sometimes as the Francis weir. It is one of the earliest forms of weirs used and really is the type from which all other forms have been developed. Because of the simplicity, ease of construction and accuracy with which the crest and sides may be set with the implements ordinarily at hand, this type of weir demands a wider use than it has received in the past few years. It is equally as accurate as the other types. The crest is placed in a horizontal position and the sides extend vertically above the crest. The angle formed therefore is a right angle, which permits the weir to be set easily and accurately by means of a carpenter's square and level. The sides must be placed carefully to give the desired length along the crest. Table 5 gives the discharge over rectangular weirs from 1 to 4 feet in length, computed from the corrected formula.

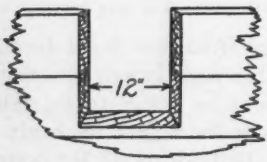

FIG. 3.—Rectangular weir.

TABLE 5.—*Discharge tables for rectangular weirs.*

Computed from the formula $Q=3.247\,lH^{1.48}-\frac{0.566\,l^{1.8}}{1+2\,l^{1.8}}\,H^{1.9}$.

Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.					Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.				
		1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	.86	10 1/8	2.46	3.72	5.01	7.59	10.19
.21	2 1/2	.312	.472	.632	.954	1.28	.87	10 1/4	2.50	3.79	5.10	7.72	10.36
.22	2 5/8	.335	.505	.677	1.02	1.37	.88	10 3/8	2.54	3.85	5.18	7.85	10.54
.23	2 3/4	.358	.539	.723	1.09	1.46	.89	10 1/2	2.58	3.92	5.27	7.99	10.71
.24	2 7/8	.380	.574	.769	1.16	1.55	.90	10 5/8	2.62	3.98	5.35	8.12	10.89
.25	3	.404	.609	.817	1.23	1.65	.91	10 3/4	2.67	4.05	5.44	8.25	11.07
.26	3 1/8	.428	.646	.865	1.31	1.75	.92	10 7/8	2.71	4.11	5.53	8.38	11.25
.27	3 1/4	.452	.682	.914	1.38	1.85	.93	11	2.75	4.18	5.62	8.52	11.43
.28	3 3/8	.477	.720	.965	1.46	1.95	.94	11 1/8	2.79	4.24	5.71	8.65	11.61
.29	3 1/2	.502	.758	1.02	1.53	2.05	.95	11 1/4	2.84	4.31	5.80	8.79	11.79
.30	3 5/8	.527	.796	1.07	1.61	2.16	.96	11 3/8	2.88	4.37	5.89	8.93	11.98
.31	3 3/4	.553	.836	1.12	1.69	2.26	.97	11 1/2	2.93	4.44	5.98	9.06	12.16
.32	3 7/8	.580	.876	1.18	1.77	2.37	.98	11 5/8	2.97	4.51	6.07	9.20	12.34
.33	4	.606	.916	1.23	1.86	2.48	.99	11 3/4	3.01	4.57	6.15	9.34	12.53
.34	4 1/8	.634	.957	1.28	1.94	2.60	1.00	12	3.06	4.64	6.25	9.48	12.72
.35	4 1/4	.661	.999	1.34	2.02	2.71	1.01	12 1/8	.....	4.71	6.34	9.62	12.91
.36	4 3/8	.688	1.04	1.40	2.11	2.82	1.02	12 1/4	.....	4.78	6.43	9.76	13.10
.37	4 1/2	.717	1.08	1.45	2.20	2.94	1.03	12 3/8	.....	4.85	6.52	9.90	13.28
.38	4 5/8	.745	1.13	1.51	2.28	3.06	1.04	12 1/2	.....	4.92	6.62	10.04	13.47
.39	4 3/4	.774	1.17	1.57	2.37	3.18	1.05	12 5/8	.....	4.98	6.71	10.18	13.66
.40	4 7/8	.804	1.21	1.63	2.46	3.30	1.06	12 3/4	.....	5.05	6.80	10.32	13.85
.41	4 7/8	.833	1.26	1.69	2.55	3.42	1.07	12 7/8	.....	5.12	6.90	10.46	14.04
.42	5 1/8	.863	1.30	1.75	2.65	3.54	1.08	13	.....	5.20	6.99	10.61	14.24
.43	5 1/8	.893	1.35	1.81	2.74	3.67	1.09	13 1/8	.....	5.26	7.09	10.75	14.43
.44	5 1/4	.924	1.40	1.88	2.83	3.80	1.10	13 1/4	.....	5.34	7.19	10.90	14.64
.45	5 3/8	.955	1.44	1.94	2.93	3.93	1.11	13 3/8	.....	5.41	7.28	11.04	14.83
.46	5 3/8	.986	1.49	2.00	3.03	4.05	1.12	13 1/2	.....	5.48	7.38	11.19	15.03
.47	5 1/2	1.02	1.54	2.07	3.12	4.18	1.13	13 5/8	.....	5.55	7.47	11.34	15.25
.48	5 5/8	1.05	1.59	2.13	3.22	4.32	1.14	13 3/4	.....	5.62	7.57	11.48	15.42
.49	5 5/8	1.08	1.64	2.20	3.32	4.45	1.15	13 7/8	.....	5.69	7.66	11.64	15.62
.50	6	1.11	1.68	2.26	3.42	4.58	1.16	13 7/8	.....	5.77	7.76	11.79	15.82
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.17	14	.....	5.84	7.86	11.94	16.02
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.18	14 1/8	.....	5.91	7.96	12.09	16.23
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.19	14 1/4	.....	5.98	8.06	12.24	16.43
.54	6 3/8	1.25	1.89	2.53	3.83	5.13	1.20	14 3/8	.....	6.06	8.16	12.39	16.63
.55	6 1/2	1.28	1.94	2.60	3.94	5.27	1.21	14 1/2	.....	6.13	8.26	12.54	16.83
.56	6 5/8	1.31	1.99	2.67	4.04	5.42	1.22	14 5/8	.....	6.20	8.35	12.69	17.06
.57	6 3/4	1.35	2.04	2.74	4.15	5.56	1.23	14 3/4	.....	6.28	8.46	12.85	17.25
.58	6 3/4	1.38	2.09	2.81	4.26	5.70	1.24	14 7/8	.....	6.35	8.56	12.99	17.45
.59	7 1/8	1.42	2.15	2.88	4.36	5.85	1.25	15	.....	6.43	8.66	13.14	17.65
.60	7 1/8	1.45	2.20	2.96	4.47	6.00	1.26	15 1/8	.....	.....	.....	13.30	17.87
.61	7 1/4	1.49	2.25	3.03	4.59	6.14	1.27	15 1/4	.....	.....	.....	13.45	18.07
.62	7 3/8	1.52	2.31	3.10	4.69	6.29	1.28	15 3/8	.....	.....	.....	13.61	18.28
.63	7 3/8	1.56	2.36	3.17	4.81	6.44	1.29	15 3/8	.....	.....	.....	13.77	18.50
.64	7 1/2	1.60	2.42	3.25	4.92	6.59	1.30	15 5/8	.....	.....	.....	13.93	18.71
.65	7 5/8	1.63	2.47	3.32	5.03	6.75	1.31	15 3/4	.....	.....	.....	14.09	18.92
.66	7 3/4	1.67	2.53	3.40	5.15	6.90	1.32	15 7/8	.....	.....	.....	14.24	19.12
.67	7 7/8	1.71	2.59	3.47	5.26	7.05	1.33	15 7/8	.....	.....	.....	14.40	19.34
.68	7 7/8	1.74	2.64	3.56	5.38	7.21	1.34	16	.....	.....	.....	14.56	19.55
.69	8	1.78	2.70	3.63	5.49	7.36	1.35	16 1/8	.....	.....	.....	14.72	19.77
.70	8 1/8	1.82	2.76	3.71	5.61	7.52	1.36	16 1/4	.....	.....	.....	14.88	19.98
.71	8 1/4	1.86	2.81	3.78	5.73	7.68	1.37	16 3/8	.....	.....	.....	15.04	20.20
.72	8 3/8	1.90	2.87	3.86	5.85	7.84	1.38	16 3/8	.....	.....	.....	15.20	20.42
.73	8 3/8	1.93	2.93	3.94	5.97	8.00	1.39	16 1/2	.....	.....	.....	15.36	20.64
.74	8 1/2	1.97	2.99	4.02	6.09	8.17	1.40	16 5/8	.....	.....	.....	15.53	20.86
.75	9	2.01	3.05	4.10	6.21	8.33	1.41	16 3/4	.....	.....	.....	15.69	21.08
.76	9 1/8	2.05	3.11	4.18	6.33	8.49	1.42	17	.....	.....	.....	15.85	21.29
.77	9 1/4	2.09	3.17	4.26	6.45	8.66	1.43	17 1/8	.....	.....	.....	16.02	21.52
.78	9 3/8	2.13	3.23	4.34	6.58	8.82	1.44	17 1/4	.....	.....	.....	16.19	21.74
.79	9 3/8	2.17	3.29	4.42	6.70	8.99	1.45	17 3/8	.....	.....	.....	16.34	21.96
.80	9 1/2	2.21	3.35	4.51	6.83	9.16	1.46	17 1/2	.....	.....	.....	16.51	22.18
.81	9 5/8	2.25	3.41	4.59	6.95	9.33	1.47	17 5/8	.....	.....	.....	16.68	22.41
.82	9 3/4	2.29	3.47	4.67	7.08	9.50	1.48	17 3/4	.....	.....	.....	16.85	22.64
.83	9 7/8	2.33	3.54	4.75	7.21	9.67	1.49	17 7/8	.....	.....	.....	17.01	22.85
.84	10 1/8	2.37	3.60	4.84	7.33	9.84	1.50	18	.....	.....	.....	17.17	23.08
.85	10 1/8	2.41	3.66	4.92	7.46	10.01							

CIPOLLETTI WEIRS.

This type of weir is trapezoidal in shape, but the name "Cipolletti" is that of the Italian engineer who proposed its use. As shown in figure 4, the crest of the weir must be level, and the sides placed on a slope of 1 to 4, meaning one unit horizontal to four units vertical. The notch therefore is larger than a rectangle with the same crest length.

It is seen readily that the Cipolletti type of weir, or in fact any weir having sloping sides, is neither so easy to construct nor so easy to check later for accuracy as is the rectangular weir. The great popularity of the Cipolletti weir is due somewhat to its having been proposed at a time when the use of weirs for measuring irrigation water was being considered, but principally because the angle which the sides make with the crest was supposed to make the flow over the weir proportional to the length of the crest. In other words, the flow for a certain head on a 2-foot weir was supposed to be twice the flow over a 1-foot weir for the same depth of water, which would require but a simple weir table for field use. Recent experiments, however, prove that the flow over Cipolletti weirs is not proportional to the length of the crest, which apparently refutes the principal argument in its favor. However, if the sides are placed properly with respect to the crest, and other conditions are observed fully the flow can be measured as accurately over a Cipolletti weir as over a rectangular weir, if the accompanying weir tables, or formula, are used. It is all right, therefore, to use a Cipolletti weir if constructed properly, but where a weir is to be constructed, the rectangular should be chosen in preference to the Cipolletti type. Table 6 gives the discharge over Cipolletti weirs from 1 to 4 feet in length, computed from the corrected formula.

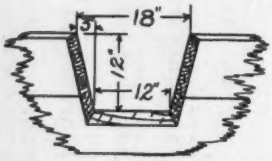

FIG. 4.—Cipolletti or trapezoidal weir.

TABLE 6.—*Discharge tables for Cipolletti weirs.*

Computed from the formula $Q=3.247\ lH^{1.48}-\frac{0.566\ l^{1.3}}{1+2\ l^{1.3}}H^{1.9}+0.609\ H^{2.5}$.

Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.					Head in feet.	Head in inches.	Discharge in cubic feet per second for crests of various lengths.				
		1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.			1 foot.	1.5 feet.	2 feet.	3 feet.	4 feet.
0.20	2 3/8	0.30	0.45	0.60	0.90	1.20	.86	10 5/16	2.87	4.14	5.43	8.01	10.60
.21	2 1/2	.32	.48	.64	.97	1.29	.87	10 7/16	2.93	4.22	5.52	8.15	10.79
.22	2 5/8	.35	.52	.69	1.04	1.38	.88	10 1/2	2.98	4.29	5.62	8.30	10.98
.23	2 3/4	.37	.55	.74	1.11	1.47	.89	10 9/16	3.04	4.37	5.72	8.44	11.17
.24	2 7/8	.39	.59	.79	1.18	1.57	.90	10 5/8	3.09	4.45	5.82	8.59	11.36
.25	3	.42	.63	.84	1.25	1.67	.91	10 11/16	3.15	4.53	5.92	8.73	11.55
.26	3 1/8	.45	.67	.89	1.33	1.77	.92	10 3/4	3.20	4.60	6.02	8.88	11.74
.27	3 1/4	.47	.70	.94	1.40	1.87	.93	10 13/16	3.26	4.68	6.13	9.03	11.94
.28	3 3/8	.50	.74	.99	1.48	1.97	.94	10 7/8	3.32	4.76	6.23	9.17	12.13
.29	3 1/2	.53	.79	1.04	1.56	2.08	.95	10 15/16	3.37	4.84	6.33	9.32	12.33
.30	3 5/8	.56	.83	1.10	1.64	2.19	.96	11	3.43	4.92	6.44	9.48	12.53
.31	3 3/4	.59	.87	1.15	1.73	2.30	.97	11 1/16	3.49	5.00	6.55	9.62	12.72
.32	3 13/16	.61	.91	1.21	1.80	2.41	.98	11 1/8	3.55	5.09	6.64	9.78	12.92
.33	3 15/16	.64	.95	1.27	1.89	2.52	.99	11 3/16	3.61	5.17	6.75	9.93	13.12
.34	4 1/16	.67	1.00	1.32	1.98	2.64	1.00	12	3.67	5.25	6.86	10.08	13.32
.35	4 1/8	.70	1.04	1.38	2.07	2.75	1.01	12 1/16	.....	5.33	6.96	10.24	13.53
.36	4 1/4	.73	1.09	1.44	2.16	2.87	1.02	12 1/8	.....	5.42	7.07	10.40	13.73
.37	4 5/16	.77	1.13	1.50	2.25	2.99	1.03	12 3/16	.....	5.50	7.18	10.55	13.94
.38	4 7/16	.80	1.18	1.57	2.34	3.11	1.04	12 1/4	.....	5.59	7.29	10.71	14.15
.39	4 1/2	.83	1.23	1.63	2.43	3.24	1.05	12 5/16	.....	5.67	7.40	10.87	14.35
.40	4 5/8	.87	1.28	1.69	2.53	3.36	1.06	12 3/8	.....	5.76	7.51	11.03	14.56
.41	4 11/16	.90	1.32	1.76	2.62	3.49	1.07	12 7/16	.....	5.84	7.62	11.18	14.76
.42	4 13/16	.93	1.37	1.82	2.72	3.61	1.08	12 1/2	.....	5.93	7.73	11.35	14.98
.43	4 15/16	.97	1.42	1.89	2.81	3.74	1.09	12 9/16	.....	6.02	7.84	11.51	15.19
.44	5 1/16	1.00	1.47	1.95	2.91	3.87	1.10	12 5/8	.....	6.11	7.96	11.68	15.41
.45	5 1/8	1.04	1.53	2.02	3.01	4.01	1.11	12 11/16	.....	6.20	8.07	11.84	15.62
.46	5 1/4	1.07	1.58	2.09	3.11	4.14	1.12	12 3/4	.....	6.29	8.18	12.00	15.84
.47	5 5/16	1.11	1.63	2.16	3.21	4.28	1.13	12 13/16	.....	6.37	8.29	12.16	16.04
.48	5 7/16	1.15	1.68	2.23	3.32	4.41	1.14	12 7/8	.....	6.46	8.41	12.33	16.26
.49	5 1/2	1.18	1.74	2.30	3.42	4.55	1.15	12 15/16	.....	6.56	8.53	12.50	16.48
.50	6	1.22	1.79	2.37	3.53	4.69	1.16	13	.....	6.65	8.65	12.67	16.70
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.17	13 1/16	.....	6.74	8.76	12.84	16.93
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.18	13 1/8	.....	6.83	8.88	13.01	17.15
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.19	13 3/16	.....	6.93	9.10	13.18	17.37
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.20	13 1/4	.....	7.02	9.12	13.35	17.59
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.21	13 5/16	.....	7.11	9.24	13.52	17.81
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.22	13 3/8	.....	7.20	9.36	13.69	18.03
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.23	13 7/16	.....	7.30	9.48	13.87	18.27
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.24	13 1/2	.....	7.40	9.60	14.04	18.49
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.25	15	.....	7.49	9.72	14.21	18.71
.60	7 1/8	1.62	2.37	3.13	4.64	6.17	1.26	15 1/16	.....	.....	.....	14.39	18.95
.61	7 1/4	1.67	2.43	3.20	4.76	6.32	1.27	15 1/8	.....	.....	.....	14.56	19.17
.62	7 5/16	1.71	2.49	3.28	4.88	6.47	1.28	15 3/16	.....	.....	.....	14.74	19.41
.63	7 7/16	1.75	2.55	3.37	5.00	6.63	1.29	15 1/4	.....	.....	.....	14.92	19.65
.64	7 1/2	1.80	2.62	3.45	5.12	6.79	1.30	15 5/16	.....	.....	.....	15.11	19.88
.65	7 5/8	1.84	2.68	3.53	5.24	6.95	1.31	15 3/8	.....	.....	.....	15.29	20.12
.66	7 11/16	1.89	2.75	3.61	5.36	7.11	1.32	15 7/16	.....	.....	.....	15.46	20.34
.67	7 13/16	1.93	2.81	3.70	5.48	7.28	1.33	15 1/2	.....	.....	.....	15.64	20.58
.68	7 15/16	1.98	2.87	3.79	5.61	7.44	1.34	16 1/16	.....	.....	.....	15.82	20.82
.69	8 1/16	2.02	2.94	3.87	5.73	7.61	1.35	16 1/8	.....	.....	.....	16.01	21.06
.70	8 1/8	2.07	3.01	3.95	5.86	7.77	1.36	16 3/16	.....	.....	.....	16.19	21.29
.71	8 1/4	2.12	3.07	4.04	5.99	7.94	1.37	16 1/4	.....	.....	.....	16.37	21.53
.72	8 5/16	2.16	3.14	4.13	6.12	8.11	1.38	16 5/16	.....	.....	.....	16.57	21.78
.73	8 7/16	2.21	3.21	4.22	6.24	8.28	1.39	16 3/8	.....	.....	.....	16.75	22.02
.74	8 1/2	2.26	3.28	4.31	6.38	8.45	1.40	16 7/16	.....	.....	.....	16.94	22.27
.75	9	2.31	3.35	4.40	6.51	8.62	1.41	16 1/2	.....	.....	.....	17.13	22.51
.76	9 1/8	2.36	3.42	4.49	6.64	8.80	1.42	17 1/16	.....	.....	.....	17.31	22.75
.77	9 1/4	2.41	3.49	4.58	6.77	8.97	1.43	17 1/8	.....	.....	.....	17.51	23.01
.78	9 3/8	2.46	3.56	4.67	6.90	9.15	1.44	17 1/4	.....	.....	.....	17.70	23.26
.79	9 1/2	2.51	3.63	4.76	7.04	9.33	1.45	17 3/8	.....	.....	.....	17.89	23.50
.80	9 5/8	2.56	3.70	4.85	7.18	9.51	1.46	17 1/2	.....	.....	.....	18.08	23.75
.81	9 3/4	2.61	3.77	4.95	7.31	9.69	1.47	17 5/8	.....	.....	.....	18.28	24.01
.82	9 13/16	2.66	3.84	5.04	7.45	9.87	1.48	17 3/4	.....	.....	.....	18.47	24.26
.83	9 15/16	2.71	3.92	5.14	7.59	10.05	1.49	17 7/8	.....	.....	.....	18.66	24.50
.84	10 1/16	2.77	3.99	5.23	7.73	10.23	1.50	18	.....	.....	.....	18.85	24.75
.85	10 1/8	2.82	4.07	5.33	7.87	10.42							

90° TRIANGULAR-NOTCH WEIRS.

This type of weir deserves to be more widely used than at present for the measurement of small quantities of water to the irrigator. If the fall is available it may be used for flows as great as 14 second-feet, which would be obtained with a depth of practically 2 feet of water above the vertex, or lowest point, of the angle formed by the sides. However, conditions usually are not favorable for its use for such large heads, and Table 7 gives the discharge for heads up to 1.25 feet. Since the sides meet at a point with no length of crest, a small flow of water that would not pass over one of the other weirs without adhering to the crest and therefore making the measurement worthless, will flow free in the 90° triangular notch and may be measured accurately. The 90° triangular notch is especially applicable from the smallest flow up to 2 or 3 cubic feet per second. Because of the greater depth of water required for this type of weir to discharge a given quantity of water, and the consequent greater loss of grade, one of the other types of weirs usually will be better adapted to large quantities of water.

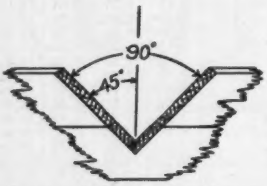

FIG. 5.—Ninety-degree triangular notch weir.

Experiments have shown that the rectangular and Cipolletti weirs with 6-inch crest lengths do not follow the same laws of discharge as the longer weirs, and the discharge formulas given in this bulletin for these weirs do not apply to weirs with a crest length of 6 inches. Therefore, where only a small flow of water is to be measured the use of the 90° triangular notch is especially recommended.

The sides of the 90° triangular notch may be set readily by means of a carpenter's square and level. The notch can be marked out properly by placing the point of the angle between the arms of a carpenter's square at a point which is to be the bottom of the notch and adjusting the square so that the same figures on both arms of the square are at the edge of the board, then if the board is set level the notch will be in the proper position. The sides, therefore, have the same slope.

Table 7 gives the discharge over the 90° triangular notch, computed from the corrected formula.

TABLE 7.—*Discharge table for 90° triangular notch.*

Computed from the formula $Q=2.49\ H^{2.48}$.

Head in feet.	Head in inches.	Discharge in second-feet (Q).	Head in feet.	Head in inches.	Discharge in second-feet (Q).	Head in feet.	Head in inches.	Discharge in second-feet (Q).
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 1/8	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 1/8	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 3/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 5/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 7/16	.790	.98	11 3/4	2.37
.29	3 1/2	.115	.64	7 1/2	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 5/8	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 13/16	.887	1.01	12 1/8	2.55
.32	3 13/16	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 1/8	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
.35	4 1/8	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 3/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 5/16	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 7/16	.226	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 1/2	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 5/8	.256	.75	9	1.22	1.10	13 1/8	3.15
.41	4 3/4	.272	.76	9 1/8	1.26	1.11	13 3/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 5/16	3.30
.43	5 1/8	.306	.78	9 3/8	1.34	1.13	13 7/16	3.37
.44	5 1/4	.324	.79	9 1/2	1.39	1.14	13 1/2	3.44
.45	5 3/8	.343	.80	9 5/8	1.43	1.15	13 5/8	3.52
.46	5 1/2	.362	.81	9 3/4	1.48	1.16	13 3/4	3.59
.47	5 5/8	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 3/4	.403	.83	9 15/16	1.57	1.18	14 1/8	3.75
.49	5 7/8	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 1/8	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 3/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 5/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 7/16	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 1/2	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

UNITS OF MEASURE.

The *cubic-foot per second*, called second-foot, is a unit of measure for flowing water. When a stream discharges 1 cubic foot of water in one second there is a second-foot flow.

The *acre-foot* is a unit of measure for standing water, and is that volume which will cover 1 acre 1 foot deep. An acre-inch is $\frac{1}{12}$ of an acre-foot, or the volume which will cover 1 acre to a depth of 1 inch.

The *miner's inch* is unsatisfactory and rapidly losing favor as a unit for measuring water, because it is not a definite quantity. It varies with the conditions under which it is used, and therefore is being replaced by the second-foot. In several of the Western States the miner's inch has been defined by law as being a certain fractional part of a second-foot, and these values are given in the accompanying table of hydraulic equivalents.

TABLE OF HYDRAULIC EQUIVALENTS.

1 cubic foot equals 7.48 gallons, or approximately 7½ gallons.
1 cubic foot of water weighs approximately 62½ pounds.
1 cubic foot per second equals 448.83 gallons per minute, or approximately 450 gallons per minute.
1 cubic foot per second flowing for 1 hour equals approximately 1 acre-inch.
1 cubic foot per second flowing for 12 hours equals appromiately 1 acre-foot.
1 cubic-foot per second flowing for 24 hours equals approximately 2 acre-feet.
1 acre-foot equals 43,560 cubic feet, equals 325,851 gallons.
1,000,000 cubic feet equals 22.95 acre-feet.

In Arizona, Nevada, Montana, Oregon, and central California 1 miner's inch (statutory inch) equals $\frac{1}{40}$ of 1 cubic foot per second.

In southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska, and Utah 1 miner's inch (statutory inch) equals $\frac{1}{50}$ of 1 cubic foot per second.

In Colorado it is generally assumed that 1 miner's inch (statutory inch) equals 1/38.4 of 1 cubic foot per second.

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CONSTRUCTION AND USE OF FARM WEIRS

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UNITED STATES
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CONSTRUCTION AND USE OF FARM WEIRS

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NEED OF FARM WEIRS

In the arid west vast sums of money have been expended in the construction of ditch and canal systems to carry water to the lands where the rainfall is either insufficient or too uncertain for profitable agriculture, and the farmers have spent a still greater amount for preparing the land for irrigation and for purchasing "water rights," which entitle them to a certain amount of water. The value of the water has increased with the development of the country and now there is a general demand that the water be measured from the ditch to the irrigator as well as from the stream to the main canal. This is an important step toward better business methods in the management of canal systems and farms, and calls for accurate and reliable information concerning devices suited to the measurement of comparatively small streams of flowing water.

DEFINITIONS

The "weir" is one of the most commonly used devices for this purpose. A bulkhead or wall built across a ditch or stream, with an opening cut in the top of the wall through which the water is allowed to pass, is called a "weir" and the opening is called the "weir notch." The bottom or horizontal edge of the notch is called the "weir crest." The portion of the ditch immediately upstream from the bulkhead is the "weir box" or "weir pond." The height of the water surface in the weir pond above the weir crest is the "head." When the water flows over the crest into the air before it strikes the surface of the water in the ditch downstream from the bulkhead, it is said to have "free fall." The weir notch must have a definite shape and should be of definite length, such as 1½ feet, 3 feet etc., to facilitate the use of tables for determining the quantity of water. The horizontal distance from the end of the weir crest to the side of the pond

NOTE.—The work on which this bulletin is based was done in the hydraulic laboratory at Fort Collins, Colo., under a cooperative agreement between the Office of Experiment Stations, United States Department of Agriculture, and the Colorado Agricultural Experiment Station.

For a technical report on the experimental data see Journal of Agricultural Research, Vol. V. No. 22, March 6, 1916.

The purpose of this bulletin is to give practical directions for the construction and use of the smaller sizes of weirs, such as are suited to the measurement of water on irrigated farms.

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is called "end contraction," and the vertical distance from the crest to the bottom of the pond is called "bottom contraction." When these contraction distances are great enough to cause a pondlike condition, which permits the water to approach the weir notch without any appreciable velocity, the weir is said to have "complete contractions."

The weirs described in this bulletin are the rectangular, Cipolletti, and 90° triangular-notch types, with free fall, sharp crests, and complete contractions. The discharge formulas for these weirs are not confined to the limits imposed upon old formulas. They are correct for high as well as low heads, at least within the range given in the tables.[1] However, in order to lessen the cost of materials for constructing the weirs, the dimensions of the weir boxes, as given in Table 1, are less than required for complete contractions, and therefore the discharges over these weirs will be greater than represented by the formula or discharge tables. The excess reaches a maximum of only about 1 per cent for the higher heads, and consequently can be ignored for practical conditions.

To determine the quantity of water flowing at any time, read the gauge, which gives the "head" or depth of water flowing over the weir notch, and turn to the discharge table in this bulletin for the type of weir used. If the head is measured in feet and decimals, find it in the first column, or if measured in feet and inches, find it in the second column, and following along this line to the right, find the number in the column for the length of weir crest used. This number will be the flow in cubic feet per second, which may be changed into miner's inches—or statute inches—by multiplying by the number of miner's inches equal to a cubic foot per second, as given in the table of hydraulic equivalents on the last page of this bulletin.

ADVANTAGES AND DISADVANTAGES OF WEIRS WITH COMPLETE CONTRACTIONS

The principal advantages and disadvantages of the types of weirs described herein may be stated as follows:

Advantages.—They are (1) accurate; (2) they are simple and may be constructed by the farmer; (3) they permit moss and floating trash to pass through the ditch without great danger of interfering with the measurement of the water; and (4) they are durable and require no adjustment for proper operation, for there are no working parts.

Disadvantages.—(1) They require a considerable pondage above the weir; (2) they can not be used where there is only a slight grade to the ditch; (3) they are not adapted to ditches that carry much sand and silt; and (4) practically all undesirable conditions, such as accumulation of sand and silt above the weir, water approaching the weir with very appreciable velocity, or injury to the weir crest, tend to give a greater flow of water than that indicated in the tables.

[1] A full discussion of the experiments upon which these formulas are based is contained in Journal of Agricultural Research, vol. 5, No. 23, Mar. 6, 1916.

WEIR BOX AND WEIR POND

When properly constructed either of the three types of weirs described herein is reliable and accurate for the measurement of flowing water. They may be placed in any ditch or canal having sufficient fall, but it is necessary that the ditch be made wider and deeper for some distance upstream from the weir notch. This enlargement is for the purpose of making practically a still-water condition before water flows over the weir. The weir box or weir pond, which is immediately upstream from the weir notch, has a uniform length, width,

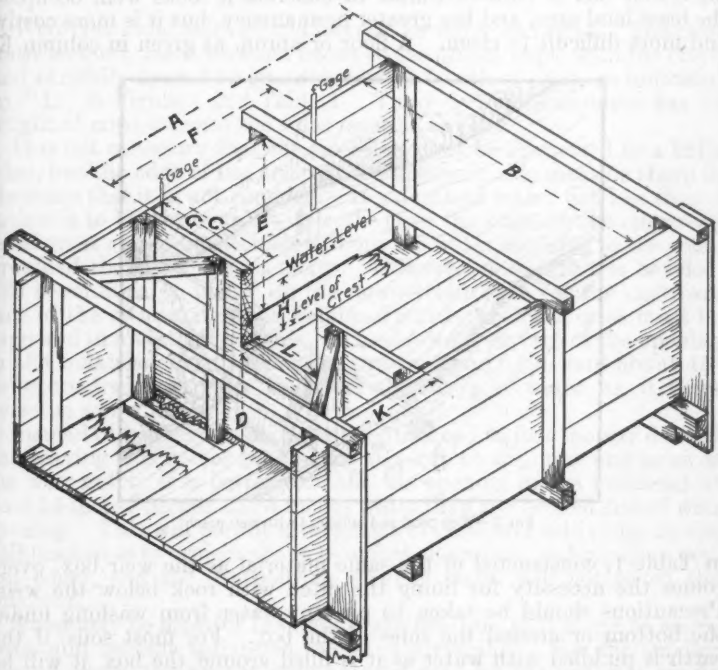

FIG. 1.—Plan of weir box.

and depth as given in Table 1, and commencing at approximately 15 feet upstream from the weir the ditch must be enlarged gradually from the regular size of the ditch to the full size of the weir box. The length of this tapering enlargement, stated as 15 feet, really needs to be greater or less as the flow in the ditch is large or small as compared to the size of the weir notch, and it will depend also upon the size of the ditch and the velocity of the water in the ditch.

Where the available grade in the ditch is not great enough to give the required depth of pond by raising the banks for a distance of 50 to 100 feet back from the weir, the bottom may be lowered and the banks raised only enough to give a free fall below the weir notch. However, the weir pond, whether a box or an enlargement of the ditch, must not be allowed to fill with silt and sediment or other

débris. The water must approach the weir in straight lines without swirling or eddy currents.

A weir box may be built as shown in Figure 1, or a bulkhead may be placed in an enlargement in the ditch as shown in Figure 2. This latter arrangement will permit cleaning of the pond with teams and scrapers, and is easy and inexpensive to construct, but because of the sloping banks the water surface must be wider than where a box is built with vertical sides. The bottom of the ditch for a short distance downstream from the weir should be lined with rock to prevent scouring due to the water falling over the weir notch. Where a complete weir box is built of timber or concrete it looks well, occupies the least land area, and has greater permanency, but it is more costly and more difficult to clean. A floor or apron, as given in column K

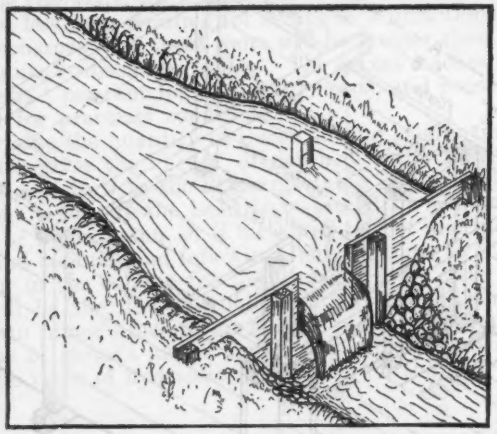

FIG. 2.—Weir pond and bulkhead with weir notch.

in Table 1, constructed of the same material as the weir box, overcomes the necessity for lining the ditch with rock below the weir. Precautions should be taken to prevent water from washing under the bottom or around the sides of the box. For most soils, if the earth is puddled with water as it is filled around the box, it will be safe; but where it is sandy or likely to wash or the ditch is subject to damage by burrowing animals a cut-off wall of sufficient size to prevent such damage should be placed under the bottom and at the sides near the upper end of the box. The height of the weir crest above the bottom of the ditch downstream from the weir notch will depend upon the size and grade of the ditch, but this height must be such that when the greatest quantity of water is flowing over the weir the water level in the ditch downstream will be below the crest. This is to permit the free passage of air between the bulkhead and the sheet of overpouring water, which is the required condition for free flow.

Table 1 (p. 9) gives the sizes of weirs best adapted to measuring flows of water varying from one-half to 22 cubic feet per second, and the proper dimensions for each size of rectangular, Cipolletti, and 90° triangular notch weirs.

As previously stated, using the weir boxes specified in Table 1 will give results within 1 per cent of correct. If smaller boxes are used the actual discharges will be larger than those given in the tables.

Tables 3 and 4 show the percentage increase in discharge caused by weir boxes smaller than required for complete contractions, for rectangular and Cipolletti weirs having crest lengths from 1 to 4 feet, and with heads of six-tenths and 1 foot.

If the smaller boxes are used discharges should be read from the tables and increased by the percentages given in Tables 3 and 4.

WEIR CRESTS AND SIDES

Weir crests and sides should be true, straight, and rigid. The crest must be level, the sides must be set to the proper angle with the crest, and carefully spaced to give the correct length of crest, as indicated by "L" in Figure 1 and Table 1. The 90° triangular notch has no length of crest because the sides meet at a point.

It is not necessary that the sides and crest be sharpened to a knife edge, but the edge of the crest on the upstream side must be sharp in the sense that it is not rounded. If a depth of water not less than 3 inches is to be run over the weir, the crest thickness on the edge may be as great as one-fourth inch without the water adhering to the crest, provided the inner edge is sharp. However, if the crest is beveled, this bevel must be placed on the downstream side, for the upstream face of the crest and of the bulkhead which holds the crest must be even and in a vertical position. The downstream face of the opening in the bulkhead must be beveled outward and downward about 45° to insure free passage of air under the sheet of water as it flows over the weir.

Instead of cutting the notch in the bulkhead to just the size desired and leaving this rather rough edge to serve as the crest and sides of the weir notch, it is better to make the opening in the bulkhead at least 1½ inches deeper and 3 inches wider than the desired size of weir opening. This will permit attachment of crest and side strips to the bulkhead so as to project about 1½ inches all around, making more perfect edges, and the overpouring sheet of water will not touch the bulkhead.

Wood may be used for the crest and sides, but, as it is apt to warp, wear, and become splintered, metal is preferable. For the smaller sizes of weirs the proper weir opening may be cut out of a single sheet of metal which may be fastened to the bulkhead. For the larger weirs crests and sides made from separate strips of metal having the edges filed true are more practical. This metal should be fairly heavy, to prevent the strips from bending and getting out of alignment easily. A more durable crest may be made of 1½-inch angle iron cut to the required lengths and set into the bottom and sides of the opening cut in the bulkhead. One face of the angle iron will be flush with the upstream side of the bulkhead and the other face will be fastened securely into the opening in the bulkhead. The edge over which the water will pass therefore will project 1½ inches from the opening in the bulkhead, and should be made true with squared edge.

If strips of wood are used for the crest and sides, they usually are fastened to the upstream face of the bulkhead for convenience, but in this case these strips must not be narrow, as this would give a pro-

jection the thickness of the strip, which will reduce the accuracy of the measurement of the water. With whatever type used the joints formed by the sides and crest must fit nicely without leaving a crack and without causing an offset.

WEIR GAUGE

The weir gauge, which is used to measure the depth of water flowing over the weir crest, may be an ordinary "ruler" or a hardwood stick graduated to feet and inches, but it is preferable to have it graduated to feet, tenths, and hundredths of a foot. It should be set upstream from the weir notch a distance ("F" in fig. 1 and Table 1) at least four times the maximum depth of water "H" to be run over the crest, or, if placed on the weir bulkhead, the distance "C," measured out from the end of the weir crest, should be at least two times the depth "H." If a complete weir box has been built, the gauge may be fastened to the bulkhead or the side of the box, as indicated in Figure 1. If, instead of a weir box, an enlargement has been made in the ditch above the bulkhead, the gauge may be attached to a solid post set just far enough from the bank to insure that it always will be in the water. If a permanent gauge is not desired, a block or other solid support should be provided at the proper distance from the weir upon which to set a scale when taking readings.

The reason for placing the gauge as described is that the depth of water "H," from which the flow over weirs is computed, is measured vertically from the weir crest to the horizontal plane of the still-water surface in the weir pond upstream from the weir. There is a decided curving downward of the water surface near the weir notch, and it is necessary to get beyond the effect of this curvature, called "draw down," in order to get the correct depth of water "H."

The zero of the gauge should be set level with the weir crest for rectangular and Cipolletti weirs and with the lowest point in the 90° triangular notch, which has no real crest; but this level should not be determined by allowing the water to start to flow over the weir crest and marking the zero of the gauge from that water level, for, in fact, the water level must be appreciably higher than the crest before it will pour over the weir. It would be better to set the gauge with a good carpenter's level and straight-edge. Furthermore, before the beginning of each irrigation season, or oftener, the position of the weir crest and sides and the gauge should be checked carefully, for frost action or settlement in the wet soil may have altered their original position and dimensions.

Where a hook gauge or an automatic recording gauge is to be used in connection with the weir, a water-tight still-box or gauge well should be provided outside of the weir box and connected to the weir box by means of a pipe laid through the bank below the level of the weir crest. The still-box should be placed upstream from the weir notch, a distance at least as great as shown in column "F" in Table 1, and should be at least 1 foot deeper than inlet of the pipe to prevent silt accumulation from stopping the free passage of water through the pipe. The pipe and box should be cleaned occasionally. The purpose of the box is to provide a still-water surface at the same level as the water in the weir box.

In order to obtain a correct measurement of the water flowing over a weir, it is very necessary that the depth of water "H" be determined accurately. This means that the gauge must be placed accurately and read carefully. The error caused by misreading the gauge 0.01 foot, or slightly less than one-eighth inch is shown in Table 2.

RECTANGULAR WEIRS

The name is taken from the shape of the weir notch, shown in Figure 3. This weir is also known sometimes as the Francis weir. It is one of the earliest forms of weirs used and really is the type from which all other forms have been developed. Because of the simplicity, ease of construction, and accuracy with which the crest and sides may be set with the implements ordinarily at hand, this type of weir demands a wider use than it has received in the past few years. It is equally as accurate as the other types. The crest is placed in a horizontal position and the sides extend vertically above the crest. The angle formed therefore is a right angle, which permits the weir to be set easily and accurately by means of a carpenter's square and level. The sides must be placed carefully to give the desired length along the crest. Table 5 gives the discharge over rectangular weirs from 1 to 4 feet in length, computed from the formula based upon accurate tests.

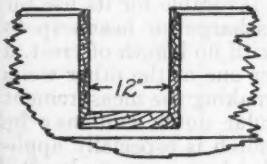

FIG. 3.—Rectangular weir.

CIPOLLETTI WEIRS

This type of weir is trapezoidal in shape, but the name "Cipolletti" is that of the Italian engineer who proposed its use. As shown in Figure 4, the crest of the weir must be level, and the sides placed on a slope of 1 to 4, meaning one unit horizontal to four units vertical. The notch is larger than a rectangle with the same crest length.

It is seen readily that the Cipolletti type of weir, or in fact any weir having sloping sides, is neither so easy to construct nor so easy to check later for accuracy as is the rectangular weir. The great popularity of the Cipolletti weir is due somewhat to its having been proposed at a time when the use of weirs for measuring irrigation water was being considered, but principally because the angle which the sides make with the crest was supposed to make the flow over the weir proportional to the length of the crest. In other words, the flow for a certain head on a 2-foot weir was supposed to be twice the flow over a 1-foot weir for the same depth of water, which would require but a simple weir table for field use. Recent experiments, however, prove that the flow over Cipolletti weirs is not proportional to the length of the crest, which apparently refutes the principal argument in its favor. However, if the sides are placed properly with respect to the crest, and other conditions are observed fully the flow can be measured as accurately over a Cipolletti weir as over a rectangular weir, if the accompanying weir tables, or formula, are used. It is all right, therefore, to use a Cipolletti weir if constructed properly, but where

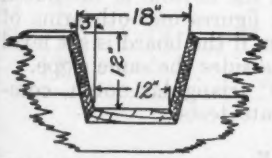

FIG. 4—Cipolletti or trapezoidal weir.

a weir is to be constructed, the rectangular should be chosen in preference to the Cipolletti type. Table 6 gives the discharge over Cipolletti weirs from 1 to 4 feet in length, computed from formula based upon accurate tests.

90° TRIANGULAR-NOTCH WEIRS

This type of weir deserves to be more widely used than at present for the measurement of small quantities of water to the irrigator. If the fall is available it may be used for flows as great as 14 second-feet, which would be obtained with a depth of practically 2 feet of water above the vertex, or lowest point, of the angle formed by the sides. However, conditions usually are not favorable for its use for such large heads, and Table 7 gives the discharge for heads up to 1.25 feet. Since the sides meet at a point with no length of crest, a small flow of water that would not pass over one of the other weirs without adhering to the crest and therefore making the measurement worthless, will flow free in the 90° triangular notch and may be measured accurately. The 90° triangular notch is especially applicable from the smallest flow up to 2 or 3 cubic feet per second. Because of the greater depth of water required for this type of weir to discharge a given quantity of water, and the consequent greater loss of grade, one of the other types of weirs usually will be better adapted to large quantities of water.

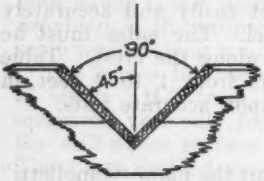

FIG. 5.—Ninety-degree triangular notch weir

Experiments have shown that the rectangular and Cipolletti weirs with 6-inch crest lengths do not follow the same laws of discharge as the longer weirs, and the discharge formulas given in this bulletin for these weirs do not apply to weirs with a crest length of 6 inches. Therefore, where only a small flow of water is to be measured the use of the 90° triangular notch is especially recommended.

The sides of the 90° triangular notch may be set readily by means of a carpenter's square and level. The notch can be marked out properly by placing the point of the angle between the arms of a carpenter's square at a point which is to be the bottom of the notch and adjusting the square so that the same figures on both arms of the square are at the edge of the board, then if the board is set level the notch will be in the proper position, the sides the same slope.

Table 7 gives the discharge over the 90° triangular notch, computed from the formula based upon accurate tests.

UNITS OF MEASURE

The *cubic foot per second*, called second-foot, is a unit of measure for flowing water. When a stream discharges 1 cubic foot of water in one second there is a second-foot flow.

The *acre-foot* is a unit of measure for standing water, and is that volume which will cover 1 acre 1 foot deep. An acre-inch is $\frac{1}{12}$ of an acre-foot, or the volume which will cover 1 acre to a depth of 1 inch.

The *miner's inch* is unsatisfactory and should lose favor as a unit for measuring water, because it is not a definite quantity. It

varies with the conditions under which it is used, and therefore is being replaced by the second-foot. In several of the Western States the miner's inch has been defined by law as being a certain fractional part of a second-foot, and these values are given in the table of hydraulic equivalents on page 14.

TABLE 1.—*Weir-box dimensions for rectangular, Cipolletti, and 90° triangular notch weirs*

[All dimensions in feet. The letters at the heads of the columns in this table refer to Figure 1]

RECTANGULAR AND CIPOLLETTI WEIRS

Flow (second-feet)	H Maximum head	L Length of weir crest	A Length of box above weir notch	K Length of box below weir notch	B Total width of box	E[1] Total depth of box	C End of crest to side	D Crest to bottom	F[2] Hook-gauge distance	G[3] Hook-gauge distance
½ to 3	1.0	1	6	2	5½	3½	2½	2	4	2
2 to 5	1.1	1½	7	3	7	4	2½	2½	4½	2
4 to 8	1.2	2	8	4	8½	4½	3½	2½	5	2½
6 to 14	1.3	3	9	5	12	5	4½	3½	5½	3
10 to 22	1.5	4	10	6	14	5½	5	3½	6	3
90° TRIANGULAR NOTCH WEIR										
½ to 2½	1.00	--------	6	2	5	3	2½	1½	4	2
2 to 4½	1.25	--------	6½	8½	6½	3½	3½	1½	5	2½

[1] This distance allows for about ½ foot freeboard above highest water level in weir box.
[2] Equals distance from crest upstream to gauge.
[3] Equals distance from end of crest over to gauge.

TABLE 2.—*Percentage of error in discharge caused by 0.01 foot error in reading the head*

Head		Length of weir crest					90° notch
		1 foot	1.5 feet	2 feet	3 feet	4 feet	
Feet	*Feet inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0.20	0 2½	7.2	7.5	7.5	7.6	7.6	----------
.30	0 3¾	5.0	5.1	5.1	5.6	4.8	8.5
.50	0 6	3.5	3.2	3.0	2.9	2.9	5.0
.70	0 8¾	2.1	1.9	2.1	2.2	2.2	3.9
.90	0 10½	1.8	1.8	1.8	1.7	1.7	2.9
1.10	1 1¼	----------	1.4	1.3	1.3	1.3	2.2
1.25	1 3	----------	----------	----------	1.1	1.1	2.1
1.50	1 6	----------	----------	----------	.9	1.0	----------

TABLE 3.—*Velocity of approach and percentage of error caused by different end and bottom contractions for rectangular weirs*

B	A	Length 1 foot				Length 1.5 feet				Length 2 feet				Length 3 feet				Length 4 feet			
Distance of bottom below crest	Distance of sides from ends of crest	Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot	
		Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error
Feet	*Feet*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
3.0	2.5			0.132	0.77																
3.0	2.0			.157	.81			0.213	0.82			0.269	0.84			0.342	0.83			0.402	0.87
3.0	1.5			.196	1.00			.260	1.08			.317	1.14			.399	1.22			.460	1.29
3.0	1.0			.260	1.40			.337	1.63			.398	1.81			.484	2.06			.543	2.22
3.0	.5			.40	2.94			.477	3.22			.540	3.44			.616	3.72			.661	3.88
2.5	2.5			.150	.74																
2.5	2.0			.178	.82			.242	.88			.302	.94			.391	1.04			.460	1.11
2.5	1.5			.224	1.05			.297	1.21			.362	1.34			.461	1.57			.528	1.69
2.5	1.0			.299	1.58			.385	1.89			.457	2.14			.553	2.50			.623	2.76
2.5	.5			.462	3.42			.549	3.73			.625	3.99			.704	4.25			.760	4.48
2.0	2.5	0.94	0.17	.175	.73																
2.0	2.0	.115	.26	.209	.84			.284	.97			.352	1.11			.458	1.30			.539	1.42
2.0	1.5	.148	.39	.261	1.13			.348	1.42			.424	1.67			.538	2.01			.620	2.28
2.0	1.0	.188	.66	.353	1.83			.450	2.28			.535	2.63			.648	3.14			.733	3.52
2.0	.5	.288	2.05	.538	4.01			.646	4.46			.728	4.80			.829	5.17			.895	5.47
1.5	2.5	.119	.17	.208	.74																
1.5	2.0	.141	.30	.252	.94	1.91	0.53	.341	1.18	0.239	0.74	.424	1.41	0.308	1.07	.539	1.71	0.365	1.33	.638	1.98
1.5	1.5	.175	.40	.314	1.31	.234	.73	.418	1.74	.286	1.01	.512	2.12	.363	1.44	.648	2.65	.416	1.74	.750	3.07
1.5	1.0	.234	.76	.424	2.24	.304	1.24	.544	2.87	.361	1.62	.646	3.40	.435	2.12	.790	4.14	.489	2.49	.889	4.68
1.5	.5	.355	2.26	.648	4.80			.784	5.53			.885	6.09	.552	3.41	1.013	6.77			1.091	7.20
1.0	2.5	.154	.19	.260	.82																
1.0	2.0	.209	.36	.314	1.12			.427	1.57			.532	2.00			.694	2.69			.810	3.15
1.0	1.5	.229	.50	.385	1.59	.311	1.09	.528	2.37	.377	1.55	.645	2.99	.478	2.25	.820	3.91	.552	2.79	.952	4.60
1.0	1.0	.308	1.01	.525	2.83	.400	1.77	.688	3.86	.476	2.39	.825	4.73	.577	3.22	.999	5.87	.650	3.83	1.135	6.77
1.0	.5	.469	2.84	.822	6.00	.573	3.74	.994	7.29	.646	4.38	1.129	8.29	.735	5.15	1.298	9.55	.794	5.64	1.405	10.27
.5	2.5	.221	.25	.350	1.11																
.5	2.0	.265	.50	.417	1.45	.368	1.30	.575	2.40	.460	2.05	.720	3.27	.624	3.34	.943	4.62	.711	4.05	1.120	5.65
.5	1.5	.337	.94	.530	2.20	.453	1.94	.710	3.53	.555	2.84	.875	4.73	.705	4.17	1.119	6.50	.818	5.15	1.308	7.88
.5	1.0	.450	1.84	.716	3.83	.588	3.22	.930	5.65	.704	4.35	1.118	7.23	.862	5.92	1.380	9.40	.975	7.01	1.576	11.2
.5	.5	.695	4.63	1.120	8.25	.852	6.43	1.37	11.0	.970	7.79	1.58	13.3	1.112	9.40	1.83	16.01	1.208	10.50	2.01	18.0

TABLE 4.—*Velocity of approach and percentage of error caused by different end and bottom contractions for Cipolletti weirs*

B	A	Length 1 foot				Length 1.5 feet				Length 2 feet				Length 3 feet				Length 4 feet			
Distance of bottom below crest	Distance of sides from ends of crest	Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot	
		Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error	Velocity of approach	Percent of error
Feet	*Feet*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
2.0	2.0	------	------	0.250	1.19	------	------	0.322	1.22	------	------	0.386	1.24	------	------	0.488	1.28	------	------	0.561	1.30
2.0	1.5	------	------	.314	1.52	------	------	.397	1.70	------	------	.467	1.84	------	------	.575	2.08	------	------	.648	2.22
2.0	1.0	------	------	.422	2.40	------	------	.514	2.80	------	------	.590	3.15	------	------	.698	3.62	------	------	.769	3.92
2.0	.5	------	------	.655	6.16	------	------	.746	6.41	------	------	.813	6.61	------	------	.896	6.88	------	------	.951	7.01
1.5	2.5																				
1.5	2.0	0.158	0.84	.300	1.34	0.207	1.02	.388	1.49	0.251	1.21	.465	1.61	0.321	1.45	.590	1.82	0.373	1.61	.680	1.98
1.5	1.5	.196	1.11	.378	1.78	.255	1.38	.477	2.10	.304	1.60	.562	2.40	.377	1.95	.693	2.85	.429	2.19	.785	3.17
1.5	1.0	.260	1.70	.508	2.89	.329	2.08	.622	3.53	.381	2.36	.714	4.06	.454	2.77	.844	4.79	.504	3.02	.937	5.31
1.5	.5	.400	3.32	.796	7.29	.469	3.83	.906	7.79	.518	4.20	.989	8.18	.580	4.66	1.094	8.64	.617	4.93	1.163	8.85
1.0	2.5																				
1.0	2.0	.205	.09	.374	1.60	.274	1.25	.489	2.06	.331	1.55	.586	2.44	.425	2.05	.758	3.13	.492	2.39	.864	3.55
1.0	1.5	.257	1.20	.471	2.20	.335	1.71	.601	2.92	.400	1.55	.710	3.55	.500	2.82	.888	4.53	.569	3.30	1.003	5.19
1.0	1.0	.344	1.84	.643	3.76	.434	2.60	.787	4.83	.501	3.17	.908	5.73	.607	4.06	1.083	7.07	.671	4.60	1.200	7.92
1.0	.5	.529	4.00	1.010	9.20	.622	4.92	1.159	10.28	.690	5.61	1.271	11.08	.770	6.41	1.410	12.09	.826	6.98	1.503	12.72
.5	2.5																				
.5	2.0	.300	1.11	.508	2.30	.399	1.81	.660	3.04	.487	2.42	.799	4.87	.625	3.40	1.013	6.73	.725	4.09	1.202	8.39
.5	1.5	.377	1.51	.640	3.30	.492	2.55	.818	4.80	.589	3.44	.969	6.09	.737	4.79	1.210	8.08	.847	5.80	1.391	9.56
.5	1.0	.505	2.39	.864	5.40	.636	3.93	1.077	7.58	.750	5.30	1.258	9.43	.908	7.18	1.505	11.95	1.013	8.39	1.688	1.38
.5	.5	.782	6.03	1.390	11.89	.932	8.02	1.605	14.63	1.037	9.43	1.782	16.85	1.173	11.28	2.015	19.80	1.263	12.48	------	------

TABLE 5.—*Discharge tables for rectangular weirs*

Computed from the formula $Q=3.247\,LH^{1.48}-\frac{0.566\,L^{1.8}}{1+2\,L^{1.8}H^{1.9}}$

Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths					Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	0.86	10 5/16	2.46	3.72	5.01	7.59	10.19
.21	2 1/2	.312	.472	.632	.954	1.28	.87	10 7/16	2.50	3.79	5.10	7.72	10.36
.22	2 5/8	.335	.505	.677	1.02	1.37	.88	10 1/2	2.54	3.85	5.18	7.85	10.54
.23	2 3/4	.358	.539	.723	1.09	1.46	.89	10 9/16	2.58	3.92	5.27	7.99	10.71
.24	2 7/8	.380	.574	.769	1.16	1.55	.90	10 5/8	2.62	3.98	5.35	8.12	10.89
.25	3	.404	.609	.817	1.23	1.65	.91	10 11/16	2.67	4.05	5.44	8.25	11.07
.26	3 1/8	.428	.646	.865	1.31	1.75	.92	11 1/16	2.71	4.11	5.53	8.38	11.25
.27	3 1/4	.452	.682	.914	1.38	1.85	.93	11 1/8	2.75	4.18	5.62	8.52	11.43
.28	3 3/8	.477	.720	.965	1.46	1.95	.94	11 1/4	2.79	4.24	5.71	8.65	11.61
.29	3 1/2	.502	.758	1.02	1.53	2.05	.95	11 3/8	2.84	4.31	5.80	8.79	11.79
.30	3 5/8	.527	.796	1.07	1.61	2.16	.96	11 7/16	2.88	4.37	5.89	8.93	11.98
.31	3 3/4	.553	.836	1.12	1.69	2.26	.97	11 1/2	2.93	4.44	5.98	9.06	12.16
.32	3 13/16	.580	.876	1.18	1.77	2.37	.98	11 9/16	2.97	4.51	6.07	9.20	12.34
.33	3 15/16	.606	.916	1.23	1.86	2.48	.99	11 5/8	3.01	4.57	6.15	9.34	12.53
.34	4 1/16	.634	.957	1.28	1.94	2.60	1.00	12	3.06	4.64	6.25	9.48	12.72
.35	4 3/16	.661	.999	1.34	2.02	2.71	1.01	12 1/8	-------	4.71	6.34	9.62	12.91
.36	4 5/16	.688	1.04	1.40	2.11	2.82	1.02	12 1/4	-------	4.78	6.43	9.76	13.10
.37	4 7/16	.717	1.08	1.45	2.20	2.94	1.03	12 3/8	-------	4.85	6.52	9.90	13.28
.38	4 1/2	.745	1.13	1.51	2.28	3.06	1.04	12 1/2	-------	4.92	6.62	10.04	13.47
.39	4 5/8	.774	1.17	1.57	2.37	3.18	1.05	12 5/8	-------	4.98	6.71	10.18	13.66
.40	4 3/4	.804	1.21	1.63	2.46	3.30	1.06	12 3/4	-------	5.05	6.80	10.32	13.85
.41	4 7/8	.833	1.26	1.69	2.55	3.42	1.07	12 7/8	-------	5.12	6.90	10.46	14.04
.42	5	.863	1.30	1.75	2.65	3.54	1.08	12 15/16	-------	5.20	6.99	10.61	14.24
.43	5 1/16	.893	1.35	1.81	2.74	3.67	1.09	13 1/16	-------	5.26	7.09	10.75	14.43
.44	5 1/8	.924	1.40	1.88	2.83	3.80	1.10	13 1/8	-------	5.34	7.19	10.90	14.64
.45	5 3/8	.955	1.44	1.94	2.93	3.93	1.11	13 3/16	-------	5.41	7.28	11.04	14.83
.46	5 1/2	.986	1.49	2.00	3.03	4.05	1.12	13 1/4	-------	5.48	7.38	11.19	15.03
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.13	13 5/16	-------	5.55	7.47	11.34	15.22
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.14	13 3/8	-------	5.62	7.57	11.48	15.42
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.15	13 7/16	-------	5.69	7.66	11.64	15.62
.50	6	1.11	1.68	2.26	3.42	4.58	1.16	13 1/2	-------	5.77	7.76	11.79	15.82
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.17	14 1/16	-------	5.84	7.86	11.94	16.02
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.18	14 1/8	-------	5.91	7.96	12.09	16.23
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.19	14 1/4	-------	5.98	8.06	12.24	16.43
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.20	14 3/8	-------	6.06	8.16	12.39	16.63
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.21	14 1/2	-------	6.13	8.26	12.54	16.83
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.22	14 5/8	-------	6.20	8.35	12.69	17.03
.57	6 7/8	1.35	2.04	2.74	4.15	5.56	1.23	14 3/4	-------	6.28	8.46	12.85	17.25
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.24	14 7/8	-------	6.35	8.56	12.99	17.45
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.25	15	-------	6.43	8.66	13.14	17.65
.60	7 1/8	1.45	2.20	2.96	4.47	6.00	1.26	15 1/8	-------	-------	-------	13.30	17.87
.61	7 3/16	1.49	2.25	3.03	4.59	6.14	1.27	15 1/4	-------	-------	-------	13.45	18.07
.62	7 5/16	1.52	2.31	3.10	4.69	6.29	1.28	15 3/8	-------	-------	-------	13.61	18.28
.63	7 7/16	1.56	2.36	3.17	4.81	6.44	1.29	15 1/2	-------	-------	-------	13.77	18.50
.64	7 1/2	1.60	2.42	3.25	4.92	6.59	1.30	15 5/8	-------	-------	-------	13.93	18.71
.65	7 5/8	1.63	2.47	3.32	5.03	6.75	1.31	15 3/4	-------	-------	-------	14.09	18.92
.66	7 3/4	1.67	2.53	3.40	5.15	6.90	1.32	15 13/16	-------	-------	-------	14.24	19.12
.67	7 7/8	1.71	2.59	3.47	5.26	7.05	1.33	15 15/16	-------	-------	-------	14.40	19.34
.68	7 15/16	1.74	2.64	3.56	5.38	7.21	1.34	16 1/16	-------	-------	-------	14.56	19.55
.69	8 1/16	1.78	2.70	3.63	5.49	7.36	1.35	16 1/8	-------	-------	-------	14.72	19.77
.70	8 1/8	1.82	2.76	3.71	5.61	7.52	1.36	16 1/4	-------	-------	-------	14.88	19.98
.71	8 3/16	1.86	2.81	3.78	5.73	7.68	1.37	16 5/16	-------	-------	-------	15.04	20.20
.72	8 5/16	1.90	2.87	3.86	5.85	7.84	1.38	16 3/8	-------	-------	-------	15.20	20.42
.73	8 7/16	1.93	2.93	3.94	5.97	8.00	1.39	16 7/16	-------	-------	-------	15.36	20.64
.74	8 1/2	1.97	2.99	4.02	6.09	8.17	1.40	16 1/2	-------	-------	-------	15.53	20.86
.75	9	2.01	3.05	4.10	6.21	8.33	1.41	16 9/16	-------	-------	-------	15.69	21.08
.76	9 1/8	2.05	3.11	4.18	6.33	8.49	1.42	17 1/16	-------	-------	-------	15.85	21.29
.77	9 1/4	2.09	3.17	4.26	6.45	8.66	1.43	17 1/8	-------	-------	-------	16.02	21.52
.78	9 3/8	2.13	3.23	4.34	6.58	8.82	1.44	17 1/4	-------	-------	-------	16.19	21.74
.79	9 1/2	2.17	3.29	4.42	6.70	8.99	1.45	17 3/8	-------	-------	-------	16.34	21.96
.80	9 5/8	2.21	3.35	4.51	6.83	9.16	1.46	17 1/2	-------	-------	-------	16.51	22.18
.81	9 3/4	2.25	3.41	4.59	6.95	9.33	1.47	17 5/8	-------	-------	-------	16.68	22.41
.82	9 13/16	2.29	3.47	4.67	7.08	9.50	1.48	17 3/4	-------	-------	-------	16.85	22.64
.83	9 15/16	2.33	3.54	4.75	7.21	9.67	1.49	17 7/8	-------	-------	-------	17.01	22.85
.84	10 1/16	2.37	3.60	4.84	7.33	9.84	1.50	18	-------	-------	-------	17.17	23.08
.85	10 1/8	2.41	3.66	4.92	7.46	10.01							

TABLE 6.—*Discharge tables for Cipolletti weirs*

Computed from the formula $Q=3.247\ LH^{1.48}-\frac{0.566L^{1.8}}{1+2L^{1.8}}H^{1.9}+0.609\ H^{2.5}$

Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths					Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
0.20	2 3/8	0.30	0.45	0.60	0.90	1.20	0.86	10 5/16	2.87	4.14	5.43	8.01	10.60
.21	2 1/2	.32	.48	.64	.97	1.29	.87	10 7/16	2.93	4.22	5.52	8.15	10.79
.22	2 5/8	.35	.52	.69	1.04	1.38	.88	10 1/2	2.98	4.29	5.62	8.30	10.98
.23	2 3/4	.37	.55	.74	1.11	1.47	.89	10 9/16	3.04	4.37	5.72	8.44	11.17
.24	2 7/8	.39	.59	.79	1.18	1.57	.90	10 5/8	3.09	4.45	5.82	8.59	11.36
.25	3	.42	.63	.84	1.25	1.67	.91	10 11/16	3.15	4.53	5.92	8.73	11.55
.26	3 1/8	.45	.67	.89	1.33	1.77	.92	10 3/4	3.20	4.60	6.02	8.88	11.74
.27	3 1/4	.47	.70	.94	1.40	1.87	.93	10 13/16	3.26	4.68	6.13	9.03	11.94
.28	3 3/8	.50	.74	.99	1.48	1.97	.94	10 7/8	3.32	4.76	6.23	9.17	12.13
.29	3 1/2	.53	.79	1.04	1.56	2.08	.95	10 15/16	3.37	4.84	6.33	9.32	12.33
.30	3 5/8	.56	.83	1.10	1.64	2.19	.96	11	3.43	4.92	6.44	9.48	12.53
.31	3 3/4	.59	.87	1.15	1.73	2.30	.97	11 1/16	3.49	5.00	6.55	9.62	12.72
.32	3 7/8	.61	.91	1.21	1.80	2.41	.98	11 1/8	3.55	5.09	6.64	9.78	12.92
.33	3 15/16	.64	.95	1.27	1.89	2.52	.99	11 3/16	3.61	5.17	6.75	9.93	13.12
.34	4 1/16	.67	1.00	1.32	1.98	2.64	1.00	12	3.67	5.25	6.86	10.08	13.32
.35	4 1/8	.70	1.04	1.38	2.07	2.75	1.01	12 1/16	-------	5.33	6.96	10.24	13.53
.36	4 1/4	.73	1.09	1.44	2.16	2.87	1.02	12 1/8	-------	5.42	7.07	10.40	13.73
.37	4 3/8	.77	1.13	1.50	2.25	2.99	1.03	12 3/16	-------	5.50	7.18	10.55	13.94
.38	4 1/2	.80	1.18	1.57	2.34	3.11	1.04	12 1/4	-------	5.59	7.29	10.71	14.15
.39	4 5/8	.83	1.23	1.63	2.43	3.24	1.05	12 5/16	-------	5.67	7.40	10.87	14.35
.40	4 3/4	.87	1.28	1.69	2.53	3.36	1.06	12 3/8	-------	5.76	7.51	11.03	14.56
.41	4 7/8	.90	1.32	1.76	2.62	3.49	1.07	12 7/16	-------	5.84	7.62	11.18	14.76
.42	5	.93	1.37	1.82	2.72	3.61	1.08	12 1/2	-------	5.93	7.73	11.35	14.96
.43	5 1/16	.97	1.42	1.89	2.81	3.74	1.09	12 9/16	-------	6.02	7.84	11.51	15.19
.44	5 1/8	1.00	1.47	1.95	2.91	3.87	1.10	12 5/8	-------	6.11	7.96	11.68	15.41
.45	5 1/4	1.04	1.53	2.02	3.01	4.01	1.11	12 11/16	-------	6.20	8.07	11.84	15.62
.46	5 5/16	1.07	1.58	2.09	3.11	4.14	1.12	12 3/4	-------	6.29	8.18	12.00	15.84
.47	5 3/8	1.11	1.63	2.16	3.21	4.28	1.13	12 13/16	-------	6.37	8.29	12.16	16.04
.48	5 1/2	1.15	1.68	2.23	3.32	4.41	1.14	12 7/8	-------	6.46	8.41	12.33	16.26
.49	5 5/8	1.18	1.74	2.30	3.42	4.55	1.15	12 15/16	-------	6.56	8.53	12.50	16.48
.50	6	1.22	1.79	2.37	3.53	4.69	1.16	13	-------	6.65	8.65	12.67	16.70
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.17	13 1/16	-------	6.74	8.76	12.84	16.93
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.18	13 1/8	-------	6.83	8.88	13.01	17.15
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.19	13 3/16	-------	6.93	9.00	13.18	17.37
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.20	13 1/4	-------	7.02	9.12	13.35	17.59
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.21	13 5/16	-------	7.11	9.24	13.52	17.81
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.22	13 3/8	-------	7.20	9.36	13.69	18.03
.57	6 7/8	1.50	2.19	2.89	4.30	5.71	1.23	13 7/16	-------	7.30	9.48	13.87	18.27
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.24	13 1/2	-------	7.40	9.60	14.04	18.49
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.25	15	-------	7.49	9.72	14.21	18.71
.60	7 1/8	1.62	2.37	3.13	4.64	6.17	1.26	15 1/16	-------	-------	-------	14.39	18.95
.61	7 1/4	1.67	2.43	3.20	4.76	6.32	1.27	15 1/8	-------	-------	-------	14.56	19.17
.62	7 5/16	1.71	2.49	3.28	4.88	6.47	1.28	15 3/16	-------	-------	-------	14.74	19.41
.63	7 3/8	1.75	2.55	3.37	5.00	6.63	1.29	15 1/4	-------	-------	-------	14.92	19.65
.64	7 1/2	1.80	2.62	3.45	5.12	6.79	1.30	15 5/16	-------	-------	-------	15.11	19.88
.65	7 5/8	1.84	2.68	3.53	5.24	6.95	1.31	15 3/8	-------	-------	-------	15.29	20.12
.66	7 3/4	1.89	2.75	3.61	5.36	7.11	1.32	15 7/16	-------	-------	-------	15.46	20.34
.67	7 7/8	1.93	2.81	3.70	5.48	7.28	1.33	15 1/2	-------	-------	-------	15.64	20.58
.68	7 15/16	1.98	2.87	3.79	5.61	7.44	1.34	15 9/16	-------	-------	-------	15.82	20.82
.69	8 1/16	2.02	2.94	3.87	5.73	7.61	1.35	15 5/8	-------	-------	-------	16.01	21.06
.70	8 1/8	2.07	3.01	3.95	5.86	7.77	1.36	15 11/16	-------	-------	-------	16.19	21.29
.71	8 1/4	2.12	3.07	4.04	5.99	7.94	1.37	15 3/4	-------	-------	-------	16.37	21.53
.72	8 5/16	2.16	3.14	4.13	6.12	8.11	1.38	15 13/16	-------	-------	-------	16.57	21.78
.73	8 3/8	2.21	3.21	4.22	6.24	8.28	1.39	15 7/8	-------	-------	-------	16.75	22.02
.74	8 7/16	2.26	3.28	4.31	6.38	8.45	1.40	15 15/16	-------	-------	-------	16.94	22.27
.75	9	2.31	3.35	4.40	6.51	8.62	1.41	16	-------	-------	-------	17.13	22.51
.76	9 1/8	2.36	3.42	4.49	6.64	8.80	1.42	16 1/16	-------	-------	-------	17.31	22.75
.77	9 1/4	2.41	3.49	4.58	6.77	8.97	1.43	16 1/8	-------	-------	-------	17.51	23.01
.78	9 3/8	2.46	3.56	4.67	6.90	9.15	1.44	16 3/16	-------	-------	-------	17.70	23.26
.79	9 1/2	2.51	3.63	4.76	7.04	9.33	1.45	16 1/4	-------	-------	-------	17.89	23.50
.80	9 5/8	2.56	3.70	4.85	7.18	9.51	1.46	16 5/16	-------	-------	-------	18.08	23.75
.81	9 3/4	2.61	3.77	4.95	7.31	9.69	1.47	16 3/8	-------	-------	-------	18.28	24.01
.82	9 13/16	2.66	3.84	5.04	7.45	9.87	1.48	16 7/16	-------	-------	-------	18.47	24.26
.83	9 15/16	2.71	3.92	5.14	7.59	10.05	1.49	16 1/2	-------	-------	-------	18.66	24.50
.84	10 1/16	2.77	3.99	5.23	7.73	10.23	1.50	18	-------	-------	-------	18.85	24.75
.85	10 1/8	2.82	4.07	5.33	7.87	10.42							

TABLE 7.—*Discharge table for 90° triangular notch*

Computed from the formula $Q=2.49\ H^{2.48}$

Head in feet	Head in inches	Discharge in second-feet (Q)	Head in feet	Head in inches	Discharge in second-feet (Q)	Head in feet	Head in inches	Discharge in second-feet (Q)
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 1/8	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 1/8	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 5/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 7/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 9/16	.790	.98	11 3/4	2.37
.27	3 1/2	.115	.64	7 11/16	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 13/16	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 15/16	.887	1.01	12 1/8	2.55
.32	3 13/16	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 1/8	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
.35	4 1/8	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 5/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 7/16	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 9/16	.226	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 11/16	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 13/16	.256	.75	9	1.22	1.10	13 1/8	3.15
.41	4 15/16	.272	.76	9 1/8	1.26	1.11	13 5/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 7/16	3.30
.43	5 1/8	.306	.78	9 3/8	1.34	1.13	13 9/16	3.37
.44	5 5/16	.324	.79	9 1/2	1.39	1.14	13 11/16	3.44
.45	5 7/16	.343	.80	9 5/8	1.43	1.15	13 13/16	3.52
.46	5 9/16	.362	.81	9 3/4	1.48	1.16	13 15/16	3.59
.47	5 11/16	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 13/16	.403	.83	9 15/16	1.57	1.18	14 1/8	3.75
.49	5 15/16	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 1/8	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 5/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 7/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 9/16	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 11/16	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

TABLE OF HYDRAULIC EQUIVALENTS

1 cubic foot equals 7.48 gallons, or approximately 7½ gallons.
1 cubic foot of water weighs approximately 62½ pounds.
1 cubic foot per second equals 448.83 gallons per minute, or approximately 450 gallons per minute.
1 cubic foot per second flowing for 1 hour equals approximately 1 acre-inch.
1 cubic foot per second flowing for 12 hours equals approximately 1 acre-foot.
1 cubic foot per second flowing for 24 hours equals approximately 2 acre-feet.
1 acre-foot equals 43,560 cubic feet, equals 325,851 gallons.
1,000,000 cubic feet equals 22.95 acre-feet.

In Arizona, Nevada, Montana, Oregon, and parts of California 1 miner's inch (statutory inch) equals $\frac{1}{40}$ of 1 cubic foot per second.

In southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska, and Utah 1 miner's inch (statutory inch) equals $\frac{1}{50}$ of 1 cubic foot per second.

In Colorado it is generally assumed that 1 cubic foot per second equals 38.4 miner's inches (statutory inches).

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FARMERS' BULLETIN 813 rev. Jan. 1926

CONSTRUCTION AND USE OF FARM WEIRS

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UNITED STATES
DEPARTMENT OF AGRICULTURE

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CONSTRUCTION AND USE OF FARM WEIRS

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NEED OF FARM WEIRS

In the arid west vast sums of money have been expended in the construction of ditch and canal systems to carry water to the lands where the rainfall is either insufficient or too uncertain for profitable agriculture, and the farmers have spent a still greater amount for preparing the land for irrigation and for purchasing "water rights," which entitle them to a certain amount of water. The value of the water has increased with the development of the country and now there is a general demand that the water be measured from the ditch to the irrigator as well as from the stream to the main canal. This is an important step toward better business methods in the management of canal systems and farms, and calls for accurate and reliable information concerning devices suited to the measurement of comparatively small streams of flowing water.

DEFINITIONS

The "weir" is one of the most commonly used devices for this purpose. A bulkhead or wall built across a ditch or stream, with an opening cut in the top of the wall through which the water is allowed to pass, is called a "weir" and the opening is called the "weir notch." The bottom or horizontal edge of the notch is called the "weir crest." The portion of the ditch immediately upstream from the bulkhead is the "weir box" or "weir pond." The height of the water surface in the weir pond above the weir crest is the "head." When the water flows over the crest into the air before it strikes the surface of the water in the ditch downstream from the bulkhead, it is said to have "free fall." The weir notch must have a definite shape and should be of definite length, such as 1½ feet, 3 feet etc., to facilitate the use of tables for determining the quantity of water. The horizontal distance from the end of the weir crest to the side of the pond

NOTE.—The work on which this bulletin is based was done in the hydraulic laboratory at Fort Collins, Colo., under a cooperative agreement between the Office of Experiment Stations, United States Department of Agriculture, and the Colorado Agricultural Experiment Station.

For a technical report on the experimental data see Journal of Agricultural Research, Vol. V. No. 23, March 6, 1916.

The purpose of this bulletin is to give practical directions for the construction and use of the smaller sizes of weirs, such as are suited to the measurement of water on irrigated farms.

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is called "end contraction," and the vertical distance from the crest to the bottom of the pond is called "bottom contraction." When these contraction distances are great enough to cause a pondlike condition, which permits the water to approach the weir notch without any appreciable velocity, the weir is said to have "complete contractions." These contraction distances should be at least equal to twice the head H.

The weirs described in this bulletin are the rectangular, Cipolletti, and 90° triangular-notch types, with free fall, sharp crests, and complete contractions. The discharge formulas for these weirs are not confined to the limits imposed upon old formulas. They are correct for high as well as low heads, at least within the range given in the tables.[1] However, in order to lessen the cost of materials for constructing the weirs, the dimensions of the weir boxes, as given in Table 1, are less than required for complete contractions, and therefore the discharges over these weirs will be greater than represented by the formula or discharge tables. The excess reaches a maximum of only about 1 per cent for the higher heads, and consequently can be ignored for practical conditions.

To determine the quantity of water flowing at any time, read the gauge, which gives the "head" or depth of water flowing over the weir notch, and turn to the discharge table in this bulletin for the type of weir used. If the head is measured in feet and decimals, find it in the first column, or if measured in feet and inches, find it in the second column, and following along this line to the right, find the number in the column for the length of weir crest used. This number will be the flow in cubic feet per second, which may be changed into miner's inches—or statute inches—by multiplying by the number of miner's inches equal to a cubic foot per second, as given in the table of hydraulic equivalents on the last page of this bulletin.

ADVANTAGES AND DISADVANTAGES OF WEIRS WITH COMPLETE CONTRACTIONS

The principal advantages and disadvantages of the types of weirs described herein may be stated as follows:

Advantages.—They are (1) accurate; (2) they are simple and may be constructed by the farmer; (3) they permit moss and floating trash to pass through the ditch without great danger of interfering with the measurement of the water; (4) they are durable and require no adjustment for proper operation, for there are no working parts; (5) a single measurement of head, H, is sufficient to determine the discharge; and (6) the weir is not easily tampered with.

Disadvantages.—(1) They require a considerable pondage above the weir; (2) they can not be used where there is only a slight grade to the ditch; (3) they are not adapted to ditches that carry much sand and silt; and (4) practically all undesirable conditions, such as accumulation of sand and silt above the weir, water approaching the weir with very appreciable velocity, or injury to the weir crest, tend to give a greater flow of water than that indicated in the tables.

[1] A full discussion of the experiments upon which these formulas are based is contained in Journal of Agricultural Research, vol. 5, No. 23, Mar. 6, 1918.

WEIR BOX AND WEIR POND

When properly constructed either of the three types of weirs described herein is reliable and accurate for the measurement of flowing water. They may be placed in any ditch or canal having sufficient fall, but it is necessary that the ditch be made wider and deeper for some distance upstream from the weir notch. This enlargement is for the purpose of making practically a still-water condition before water flows over the weir. The weir box or weir pond, which is immediately upstream from the weir notch, has a uniform length, width,

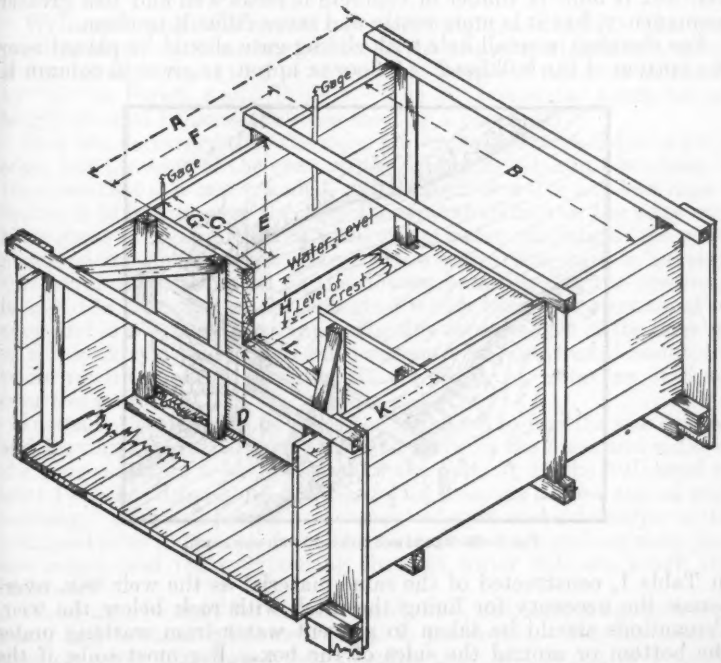

FIG. 1.—Weir box with rectangular weir notch.

and depth as given in Table 1, and commencing at approximately 15 feet upstream from the weir the ditch must be enlarged gradually from the regular size of the ditch to the full size of the weir box. The length of this tapering enlargement, stated as 15 feet, really needs to be greater or less as the flow in the ditch is large or small as compared to the size of the weir notch, and it will depend also upon the size of the ditch and the velocity of the water in the ditch.

Where the available grade in the ditch is not great enough to give the required depth of pond by raising the banks for a distance of 50 to 100 feet back from the weir, the bottom may be lowered and the banks raised only enough to give a free fall below the weir notch. However, the weir pond, whether a box or an enlargement of the ditch, must not be allowed to fill with silt and sediment or other

débris. The water must approach the weir in straight lines without swirling or eddy currents.

A weir box may be built as shown in Figure 1, or a bulkhead may be placed in an enlargement in the ditch as shown in Figure 2. This latter arrangement will permit cleaning of the pond with teams and scrapers, and is easy and inexpensive to construct, but because of the sloping banks the water surface must be wider than where a box is built with vertical sides. The bottom of the ditch for a short distance downstream from the weir should be lined to prevent scouring due to the water falling over the weir notch. Where a complete weir box is built of timber or concrete it looks well and has greater permanency, but it is more costly and more difficult to clean.

For cleaning, a small hole with sliding gate should be placed near the bottom of the bulkhead. A floor or apron, as given in column K

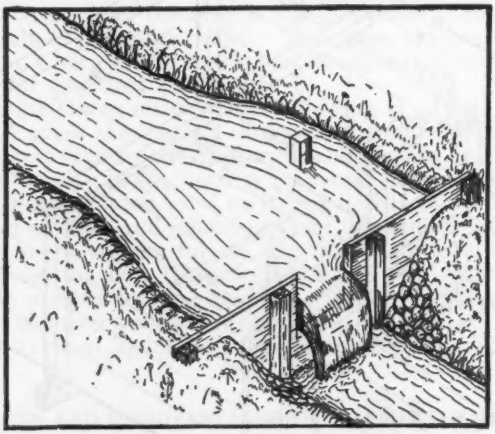

FIG. 2.—Weir pond and bulkhead with weir notch.

in Table 1, constructed of the same material as the weir box, overcomes the necessity for lining the ditch with rock below the weir. Precautions should be taken to prevent water from washing under the bottom or around the sides of the box. For most soils, if the earth is puddled with water as it is filled around the box, it will be safe; but where it is sandy or likely to wash or the ditch is subject to damage by burrowing animals a cut-off wall of sufficient size to prevent such damage should be placed under the bottom and at the sides near the upper end of the box. The height of the weir crest above the bottom of the ditch downstream from the weir notch will depend upon the size and grade of the ditch, but this height must be such that when the greatest quantity of water is flowing over the weir the water level in the ditch downstream will be below the crest. This is to permit the free passage of air between the bulkhead and the sheet of overpouring water, which is the required condition for free flow.

Table 1 (p. 9) gives the sizes of weirs best adapted to measuring flows of water varying from one-half to 22 cubic feet per second, and the proper dimensions for each size of rectangular, Cipolletti, and 90° triangular notch weirs.

As previously stated, using the weir boxes specified in Table 1 will give results within 2 per cent of correct. If smaller boxes are used the actual discharges will be larger than those given in the tables.

Tables 3 and 4 show the percentage increase in discharge caused by weir boxes smaller than required for complete contractions, for rectangular and Cipolletti weirs having crest lengths from 1 to 4 feet, and with heads of six-tenths and 1 foot.

If the smaller boxes are used discharges should be read from the tables and increased by the percentages given in Tables 3 and 4.

WEIR CRESTS AND SIDES

Weir crests and sides should be true, straight, and rigid. The crest must be level, the sides must be set to the proper angle with the crest, and carefully spaced to give the correct length of crest, as indicated by "L" in Figure 1 and Table 1. The 90° triangular notch has no length of crest because the sides meet at a point.

It is not necessary that the sides and crest be sharpened to a knife edge, but the edge of the crest on the upstream side must be sharp in the sense that it is not rounded. If a depth of water not less than 3 inches is to be run over the weir, the crest thickness on the edge may be as great as one-fourth inch without the water adhering to the crest, provided the inner edge is sharp. However, if the crest is beveled, this bevel must be placed on the downstream side, for the upstream face of the crest and of the bulkhead which holds the crest must be even and in a vertical position. The downstream face of the opening in the bulkhead must be beveled outward and downward about 45° to insure free passage of air under the sheet of water as it flows over the weir.

Instead of cutting the notch in the bulkhead to just the size desired and leaving this rather rough edge to serve as the crest and sides of the weir notch, it is better to make the opening in the bulkhead at least 1½ inches deeper and 3 inches wider than the desired size of weir opening. This will permit attachment of crest and side strips to the bulkhead so as to project about 1½ inches all around, making more perfect edges, and the overpouring sheet of water will not touch the bulkhead.

Wood may be used for the crest and sides, but, as it is apt to warp, wear, and become splintered, metal is preferable. For the smaller sizes of weirs the proper weir opening may be cut out of a single sheet of metal which may be fastened to the bulkhead. For the larger weirs crests and sides made from separate strips of metal having the edges filed true are more practical. This metal should be fairly heavy, to prevent the strips from bending and getting out of alignment easily. A more durable crest may be made of 1½-inch angle iron cut to the required lengths and set into the bottom and sides of the opening cut in the bulkhead. One face of the angle iron will be flush with the upstream side of the bulkhead and the other face will be fastened securely into the opening in the bulkhead. The edge over which the water will pass therefore will project 1½ inches from the opening in the bulkhead, and should be made true with squared edge.

If strips of wood are used for the crest and sides, they usually are fastened to the upstream face of the bulkhead for convenience, but in this case these strips must not be narrow, as this would give a pro-

jection the thickness of the strip, which will reduce the accuracy of the measurement of the water. With whatever type used the joints formed by the sides and crest must fit nicely without leaving a crack and without causing an offset.

WEIR GAUGE

The weir gauge, which is used to measure the depth of water flowing over the weir crest, may be an ordinary "ruler" or a hardwood stick graduated to feet and inches, but it is preferable to have it graduated to feet, tenths, and hundredths of a foot. It should be set upstream from the weir notch a distance ("F" in fig. 1 and Table 1) at least four times the maximum depth of water "H" to be run over the crest, or, if placed on the weir bulkhead, the distance "C," measured out from the end of the weir crest, should be at least two times the depth "H." If a complete weir box has been built, the gauge may be fastened to the bulkhead or the side of the box, as indicated in Figure 1. If, instead of a weir box, an enlargement has been made in the ditch above the bulkhead, the gauge may be attached to a solid post set just far enough from the bank to insure that it always will be in the water. If a permanent gauge is not desired, a block or other solid support should be provided at the proper distance from the weir upon which to set a scale when taking readings.

The reason for placing the gauge as described is that the depth of water "H," from which the flow over weirs is computed, is measured vertically from the weir crest to the horizontal plane of the still-water surface in the weir pond upstream from the weir. There is a decided curving downward of the water surface near the weir notch, and it is necessary to get beyond the effect of this curvature, called "draw down," in order to get the correct depth of water "H."

The zero of the gauge should be set level with the weir crest for rectangular and Cipolletti weirs and with the lowest point in the 90° triangular notch, which has no real crest; but this level should not be determined by allowing the water to start to flow over the weir crest and marking the zero of the gauge from that water level, for, in fact, the water level must be appreciably higher than the crest before it will pour over the weir. It would be better to set the gauge with a good carpenter's level and straight-edge. Furthermore, before the beginning of each irrigation season, or oftener, the position of the weir crest and sides and the gauge should be checked carefully, for frost action or settlement in the wet soil may have altered their original position and dimensions.

Where a hook gauge or an automatic recording gauge is to be used in connection with the weir, a water-tight still-box or gauge well should be provided outside of the weir box and connected to the weir box by means of a pipe laid through the bank below the level of the weir crest. The still-box should be placed upstream from the weir notch, a distance at least as great as shown in column "F" in Table 1, and should be at least 1 foot deeper than inlet of the pipe to prevent silt accumulation from stopping the free passage of water through the pipe. The pipe and box should be cleaned occasionally. The purpose of the box is to provide a still-water surface at the same level as the water in the weir box.

In order to obtain a correct measurement of the water flowing over a weir, it is very necessary that the depth of water "H" be determined accurately. This means that the gauge must be placed accurately and read carefully. The error caused by misreading the gauge 0.01 foot, or slightly less than one-eighth inch is shown in Table 2.

RECTANGULAR WEIRS

The name is taken from the shape of the weir notch, shown in Figure 3. This weir is also known sometimes as the Francis weir. It is one of the earliest forms of weirs used and really is the type from which all other forms have been developed. Because of the simplicity, ease of construction, and accuracy with which the crest and sides may be set with the implements ordinarily at hand, this type of weir demands a wider use than it has received in the past few years. It is equally as accurate as the other types. The crest is placed in a horizontal position and the sides extend vertically above the crest. The angle formed therefore is a right angle, which permits the weir to be set easily and accurately by means of a carpenter's square and level. The sides must be placed carefully to give the desired length along the crest. Table 5 gives the discharge over rectangular weirs from 1 to 4 feet in length, computed from the formula based upon accurate tests.

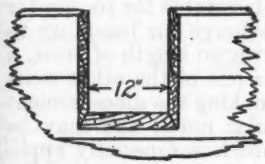

FIG. 3.—12-inch rectangular weir.

CIPOLLETTI WEIRS

This type of weir is trapezoidal in shape, but the name "Cipolletti" is that of the Italian engineer who proposed its use. As shown in Figure 4, the crest of the weir must be level, and the sides placed on a slope of 1 to 4, meaning one unit horizontal to four units vertical. The notch is larger than a rectangle with the same crest length.

It is seen readily that the Cipolletti type of weir, or in fact any weir having sloping sides, is neither so easy to construct nor so easy to check later for accuracy as is the rectangular weir. The great popularity of the Cipolletti weir is due somewhat to its having been proposed at a time when the use of weirs for measuring irrigation water was being considered, but principally because the angle which the sides make with the crest was supposed to make the flow over the weir proportional to the length of the crest. In other words, the flow for a certain head on a 2-foot weir was supposed to be twice the flow over a 1-foot weir for the same depth of water, which would require but a simple weir table for field use. Recent experiments, however, prove that the flow over Cipolletti weirs is not proportional to the length of the crest, which apparently refutes the principal argument in its favor. However, if the sides are placed properly with respect to the crest, and other conditions are observed fully the flow can be measured as accurately over a Cipolletti weir as over a rectangular weir, if the accompanying weir tables, or formula, are used. It is all right, therefore, to use a Cipolletti weir if constructed properly, but where

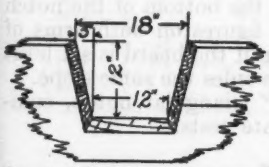

FIG. 4.—12-inch Cipolletti or trapezoidal weir.

a weir is to be constructed, the rectangular should be chosen in preference to the Cipolletti type. Table 6 gives the discharge over Cipolletti weirs from 1 to 4 feet in length, computed from formula based upon accurate tests.

90° TRIANGULAR-NOTCH WEIRS

This type of weir deserves to be more widely used than at present for the measurement of small quantities of water to the irrigator. If the fall is available it may be used for flows as great as 14 second-feet, which would be obtained with a depth of practically 2 feet of water above the vertex, or lowest point, of the angle formed by the sides. However, conditions usually are not favorable for its use for such large heads, and Table 7 gives the discharge for heads up to 1.25 feet. Since the sides meet at a point with no length of crest, a small flow of water that would not pass over one of the other weirs without adhering to the crest and therefore making the measurement worthless, will flow free in the 90° triangular notch and may be measured accurately. The 90° triangular notch is especially applicable from the smallest flow up to 2 or 3 cubic feet per second. Because of the greater depth of water required for this type of weir to discharge a given quantity of water, and the consequent greater loss of grade, one of the other types of weirs usually will be better adapted to large quantities of water.

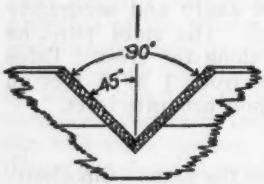

FIG. 5.—Ninety-degree triangular notch weir

Experiments have shown that the rectangular and Cipolletti weirs with 6-inch crest lengths do not follow the same laws of discharge as the longer weirs, and the discharge formulas given in this bulletin for these weirs do not apply to weirs with a crest length of 6 inches. Therefore, where only a small flow of water is to be measured the use of the 90° triangular notch is especially recommended.

The sides of the 90° triangular notch may be set readily by means of a carpenter's square and level. The notch can be marked out properly by placing the point of the angle between the arms of a carpenter's square at a point which is to be the bottom of the notch and adjusting the square so that the same figures on both arms of the square are at the edge of the board, then if the board is set level the notch will be in the proper position, the sides the same slope.

Table 7 gives the discharge over the 90° triangular notch, computed from the formula based upon accurate tests.

UNITS OF MEASURE

The *cubic foot per second*, called second-foot, is a unit of measure for flowing water. When a stream discharges 1 cubic foot of water in one second there is a second-foot flow.

The *acre-foot* is a unit of measure for standing water, and is that volume which will cover 1 acre 1 foot deep. An acre-inch is $\frac{1}{12}$ of an acre-foot, or the volume which will cover 1 acre to a depth of 1 inch.

The *miner's inch* is unsatisfactory and should lose favor as a unit for measuring water, because it is not a definite quantity. It

varies with the conditions under which it is used, and therefore is being replaced by the second-foot. In several of the Western States the miner's inch has been defined by law as being a certain fractional part of a second-foot, and these values are given in the table of hydraulic equivalents on page 14.

TABLE 1.—*Weir-box dimensions for rectangular, Cipolletti, and 90° triangular notch weirs*

[All dimensions in feet. The letters at the heads of the columns in this table refer to Figure 1]

RECTANGULAR AND CIPOLLETTI WEIRS

Flow (second-feet)	H Maximum head	L Length of weir crest	A Length of box above weir notch	K Length of box below weir notch	B Total width of box	E[1] Total depth of box	C End of crest to side	D Crest to bottom	F[2] Hook-guage distance	G[3] Hook-guage distance
½ to 3	1.0	1	6	2	5½	3½	2½	2	4	2
2 to 5	1.1	1½	7	3	7	4	2¾	2½	4½	2
4 to 8	1.2	2	8	4	8½	4½	3¼	2¾	5	2½
6 to 14	1.3	3	9	5	12	5	4½	3¼	5½	3
10 to 22	1.5	4	10	6	14	5½	5	3½	6	3

90° TRIANGULAR NOTCH WEIR

½ to 2½	1.00	--------	6	2	5	3	2½	1½	4	2
2 to 4½	1.25	--------	6½	8½	6½	3¼	3¼	1½	5	2½

[1] This distance allows for about ½ foot freeboard above highest water level in weir box.
[2] Equals distance from crest upstream to gauge. See F in Figure 1.
[3] Equals distance from end of crest over to gauge. See G in Figure 1.

TABLE 2.—*Percentage of error in discharge caused by 0.01 foot error in reading the head*

Head		Length of weir crest					90° notch
		1 foot	1.5 feet	2 feet	3 feet	4 feet	
Feet	*Feet inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0.20	0 2½	7.2	7.5	7.5	7.6	7.6	----------
.30	0 3½	5.0	5.1	5.1	5.6	4.8	8.5
.50	0 6	3.5	3.2	3.0	2.9	2.9	5.0
.70	0 8½	2.1	1.9	2.1	2.2	2.2	3.9
.90	0 10¼	1.8	1.8	1.8	1.7	1.7	2.9
1.10	1 1¼	----------	1.4	1.3	1.3	1.3	2.2
1.25	1 3	----------	----------	----------	1.1	1.1	2.1
1.50	1 6	----------	----------	----------	.9	1.0	----------

TABLE 3.—*Velocity of approach and percentage of error with different end and bottom contraction distances for rectangular weirs*

B	A	Crest length 1 foot				Crest length 1.5 feet				Crest length 2 feet				Crest length 3 feet				Crest length 4 feet			
Distance of floor of box below crest	Distance of sides of box from ends of crest	Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot	
		Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error
Feet	*Feet*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
3.0	2.5			0.13	0.77																
3.0	2.0			.16	.81			0.21	0.82			0.27	0.84			0.34	0.83			0.40	0.87
3.0	1.5			.20	1.00			.26	1.08			.32	1.14			.40	1.22			.46	1.29
3.0	1.0			.26	1.40			.34	1.63			.40	1.81			.48	2.06			.54	2.22
3.0	.5			.40	2.94			.48	3.22			.54	3.44			.62	3.72			.66	3.88
2.5	2.5			.15	.74																
2.5	2.0			.18	.82			.24	.88			.30	.94			.39	1.04			.46	1.11
2.5	1.5			.22	1.05			.30	1.21			.36	1.34			.46	1.57			.53	1.69
2.5	1.0			.30	1.58			.38	1.89			.46	2.14			.55	2.50			.62	2.76
2.5	.5			.46	3.42			.55	3.73			.62	3.99			.70	4.25			.76	4.48
2.0	2.5	0.94	0.17	.18	.73																
2.0	2.0	.12	.26	.21	.84			.28	.97			.35	1.11			.46	1.30			.54	1.42
2.0	1.5	.15	.39	.26	1.13			.35	1.42			.42	1.67			.54	2.01			.62	2.28
2.0	1.0	.19	.66	.35	1.83			.45	2.28			.54	2.63			.65	3.14			.73	3.52
2.0	.5	.29	2.05	.54	4.01			.65	4.46			.73	4.80			.83	5.17			.90	5.47
1.5	2.5	.12	.17	.21	.74																
1.5	2.0	.14	.30	.25	.94	1.91	0.53	.34	1.18	0.24	0.74	.42	1.41	0.31	1.07	.54	1.71	0.36	1.33	.64	1.98
1.5	1.5	.18	.40	.31	1.31	.23	.73	.42	1.74	.28	1.01	.51	2.12	.36	1.44	.65	2.65	.42	1.74	.75	3.07
1.5	1.0	.23	.76	.42	2.24	.30	1.24	.54	2.87	.36	1.62	.65	3.40	.44	2.12	.79	4.14	.49	2.49	.89	4.68
1.5	.5	.36	2.26	.65	4.80			.78	5.53			.88	6.09	.55	3.41	1.01	6.77			1.09	7.20
1.0	2.5	.15	.19	.26	.82																
1.0	2.0	.21	.36	.31	1.12			.43	1.57			.53	2.00			.69	2.69			.81	3.15
1.0	1.5	.23	.50	.38	1.59	.31	1.09	.53	2.37	.38	1.55	.64	2.99	.48	2.25	.82	3.91	.55	2.79	.95	4.60
1.0	1.0	.31	1.01	.52	2.83	.40	1.77	.69	3.86	.48	2.39	.82	4.73	.58	3.22	1.00	5.87	.65	3.83	1.14	6.77
1.0	.5	.47	2.84	.82	6.00	.57	3.74	.99	7.29	.65	4.38	1.13	8.29	.74	5.15	1.30	9.55	.79	5.64	1.40	10.27
.5	2.5	.22	.25	.35	1.11																
.5	2.0	.26	.50	.42	1.45	.37	1.30	.58	2.40	.46	2.05	.72	3.27	.62	3.34	.94	4.62	.71	4.05	1.12	5.65
.5	1.5	.34	.94	.53	2.20	.45	1.94	.71	3.53	.56	2.84	.88	4.73	.70	4.17	1.12	6.50	.82	5.15	1.31	7.88
.5	1.0	.45	1.84	.72	3.83	.59	3.22	.93	5.65	.70	4.35	1.12	7.23	.86	5.92	1.38	9.40	.97	7.01	1.58	11.2
.5	.5	.70	4.63	1.12	8.25	.85	6.43	1.37	11.0	.97	7.79	1.58	13.3	1.11	9.40	1.83	16.01	1.21	10.50	2.01	18.0

.5	.5	.70	4.63	1.12	8.25	.85	6.43	1.37	11.0	.97	7.79	1.58	13.3	1.11	9.40	1.83	16.01	1.21	10.50	2.01	18.0

TABLE 4.—*Velocity of approach and percentage of error with different end and bottom contraction distances for Cipolletti weirs*

B	A	Crest length 1 foot				Crest length 1.5 feet				Crest length 2 feet				Crest length 3 feet				Crest length 4 feet			
Distance of floor of box below crest	Distance of sides of box from ends of crest	Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot		Head 0.6 foot		Head 1 foot	
		Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error	Velocity of approach	Per cent of error
Feet	*Feet*	*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*		*Ft. per sec.*	
2.0	2.0	-------	-------	0.25	1.19	-------	-------	0.32	1.22	-------	-------	0.39	1.24	-------	-------	0.49	1.28	-------	-------	0.56	1.30
2.0	1.5	-------	-------	.31	1.52	-------	-------	.40	1.70	-------	-------	.47	1.84	-------	-------	.58	2.08	-------	-------	.65	2.22
2.0	1.0	-------	-------	.42	2.40	-------	-------	.51	2.80	-------	-------	.59	3.15	-------	-------	.70	3.62	-------	-------	.77	3.92
2.0	.5	-------	-------	.66	6.16	-------	-------	.75	6.41	-------	-------	.81	6.61	-------	-------	.90	6.88	-------	-------	.95	7.01
1.5	2.5	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1.5	2.0	0.16	0.84	.30	1.34	0.21	1.02	.39	1.49	0.25	1.21	.46	1.61	0.32	1.45	.59	1.82	0.37	1.61	.68	1.98
1.5	1.5	.20	1.11	.38	1.78	.26	1.38	.48	2.10	.30	1.60	.56	2.40	.38	1.95	.69	2.85	.43	2.19	.78	3.17
1.5	1.0	.26	1.70	.51	2.89	.33	2.08	.62	3.53	.38	2.36	.71	4.06	.45	2.77	.84	4.79	.50	3.02	.94	5.31
1.5	.5	.40	3.32	.80	7.29	.47	3.83	.91	7.79	.52	4.20	.99	8.18	.58	4.66	1.09	8.64	.62	4.93	1.16	8.85
1.0	2.5	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
1.0	2.0	.20	.09	.37	1.60	.27	1.25	.49	2.06	.33	1.55	.59	2.44	.42	2.05	.76	3.13	.49	2.39	.86	3.55
1.0	1.5	.26	1.20	.47	2.20	.34	1.71	.60	2.92	.40	1.55	.71	3.55	.50	2.82	.89	4.53	.57	3.30	1.00	5.19
1.0	1.0	.34	1.84	.64	3.76	.43	2.60	.79	4.83	.50	3.17	.91	5.73	.61	4.06	1.08	7.07	.67	4.60	1.20	7.92
1.0	.5	.53	4.00	1.01	9.20	.62	4.92	1.16	10.28	.69	5.61	1.27	11.08	.77	6.41	1.41	12.09	.83	6.98	1.50	12.72
.5	2.5	-------	-------	.64	3.3	-------	-------	.82	4.8	-------	-------	.97	6.07	-------	-------	1.21	8.07	-------	-------	1.39	9.56
.5	2.0	.30	1.11	.51	2.30	.40	1.81	.66	2.64	.49	2.42	.80	4.87	.63	3.40	1.01	6.73	.73	4.09	1.20	8.39
.5	1.5	.38	1.51	.64	3.30	.49	2.55	.82	4.80	.59	3.44	.97	6.09	.74	4.79	1.21	8.08	.85	5.80	1.39	9.56
.5	1.0	.50	2.39	.86	5.40	.64	3.93	1.08	7.58	.75	5.30	1.26	9.43	.91	7.18	1.50	11.95	1.01	8.39	1.69	1.38
.5	.5	.78	6.03	1.39	11.89	.93	8.02	1.60	14.63	1.04	9.43	1.78	16.85	1.17	11.28	2.02	19.80	1.26	12.48	-------	-------

TABLE 5.—*Discharge tables for rectangular weirs with complete contractions*

Computed from the formula $Q=3.247LH^{1.48}-\frac{0.566\ L^{1.8}}{1+2\ L^{1.8}H^{1.8}}$

Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths					Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	0.86	10 5/16	2.46	3.72	5.01	7.59	10.19
.21	2 1/2	.312	.472	.632	.954	1.28	.87	10 7/16	2.50	3.79	5.10	7.72	10.36
.22	2 5/8	.335	.505	.677	1.02	1.37	.88	10 1/2	2.54	3.85	5.18	7.85	10.54
.23	2 3/4	.358	.539	.723	1.09	1.46	.89	10 5/8	2.58	3.92	5.27	7.99	10.71
.24	2 7/8	.380	.574	.769	1.16	1.55	.90	10 3/4	2.62	3.98	5.35	8.12	10.89
.25	3	.404	.609	.817	1.23	1.65	.91	10 7/8	2.67	4.05	5.44	8.25	11.07
.26	3 1/8	.428	.646	.865	1.31	1.75	.92	11	2.71	4.11	5.53	8.38	11.25
.27	3 1/4	.452	.682	.914	1.38	1.85	.93	11 1/8	2.75	4.18	5.62	8.52	11.43
.28	3 3/8	.477	.720	.965	1.46	1.95	.94	11 1/4	2.79	4.24	5.71	8.65	11.61
.29	3 1/2	.502	.758	1.02	1.53	2.05	.95	11 3/8	2.84	4.31	5.80	8.79	11.79
.30	3 5/8	.527	.796	1.07	1.61	2.16	.96	11 1/2	2.88	4.37	5.89	8.93	11.98
.31	3 3/4	.553	.836	1.12	1.69	2.26	.97	11 5/8	2.93	4.44	5.98	9.06	12.16
.32	3 7/8	.580	.876	1.18	1.77	2.37	.98	11 3/4	2.97	4.51	6.07	9.20	12.34
.33	3 15/16	.606	.916	1.23	1.86	2.48	.99	11 7/8	3.01	4.57	6.15	9.34	12.53
.34	4 1/16	.634	.957	1.28	1.94	2.60	1.00	12	3.06	4.64	6.25	9.48	12.72
.35	4 1/8	.661	.999	1.34	2.02	2.71	1.01	12 1/8	-------	4.71	6.34	9.62	12.91
.36	4 1/4	.688	1.04	1.40	2.11	2.82	1.02	12 1/4	-------	4.78	6.43	9.76	13.10
.37	4 3/8	.717	1.08	1.45	2.20	2.94	1.03	12 3/8	-------	4.85	6.52	9.90	13.28
.38	4 1/2	.745	1.13	1.51	2.28	3.06	1.04	12 1/2	-------	4.92	6.62	10.04	13.47
.39	4 5/8	.774	1.17	1.57	2.37	3.18	1.05	12 5/8	-------	4.98	6.71	10.18	13.66
.40	4 3/4	.804	1.21	1.63	2.46	3.30	1.06	12 3/4	-------	5.05	6.80	10.32	13.85
.41	4 7/8	.833	1.26	1.69	2.55	3.42	1.07	12 13/16	-------	5.12	6.90	10.46	14.04
.42	5 1/16	.863	1.30	1.75	2.65	3.54	1.08	12 7/8	-------	5.20	6.99	10.61	14.24
.43	5 1/4	.893	1.35	1.81	2.74	3.67	1.09	13 1/16	-------	5.26	7.09	10.75	14.43
.44	5 5/16	.924	1.40	1.88	2.83	3.80	1.10	13 1/8	-------	5.34	7.19	10.90	14.64
.45	5 3/8	.955	1.44	1.94	2.93	3.93	1.11	13 1/4	-------	5.41	7.28	11.04	14.83
.46	5 1/2	.986	1.49	2.00	3.03	4.05	1.12	13 5/16	-------	5.48	7.38	11.19	15.03
.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.13	13 3/8	-------	5.55	7.47	11.34	15.22
.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.14	13 1/2	-------	5.62	7.57	11.48	15.42
.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.15	13 5/8	-------	5.69	7.66	11.64	15.62
.50	6	1.11	1.68	2.26	3.42	4.58	1.16	13 3/4	-------	5.77	7.76	11.79	15.82
.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.17	14 1/16	-------	5.84	7.86	11.94	16.02
.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.18	14 1/8	-------	5.91	7.96	12.09	16.23
.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.19	14 1/4	-------	5.98	8.06	12.24	16.43
.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.20	14 3/8	-------	6.06	8.16	12.39	16.63
.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.21	14 1/2	-------	6.13	8.26	12.54	16.83
.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.22	14 5/8	-------	6.20	8.35	12.69	17.03
.57	6 7/8	1.35	2.04	2.74	4.15	5.56	1.23	14 3/4	-------	6.28	8.46	12.85	17.25
.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.24	14 7/8	-------	6.35	8.56	12.99	17.45
.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.25	15	-------	6.43	8.66	13.14	17.65
.60	7 1/8	1.45	2.20	2.96	4.47	6.00	1.26	15 1/8	-------	-------	-------	13.30	17.87
.61	7 1/4	1.49	2.25	3.03	4.59	6.14	1.27	15 1/4	-------	-------	-------	13.45	18.07
.62	7 5/16	1.52	2.31	3.10	4.69	6.29	1.28	15 3/8	-------	-------	-------	13.61	18.28
.63	7 3/8	1.56	2.36	3.17	4.81	6.44	1.29	15 1/2	-------	-------	-------	13.77	18.50
.64	7 1/2	1.60	2.42	3.25	4.92	6.59	1.30	15 5/8	-------	-------	-------	13.93	18.71
.65	7 5/8	1.63	2.47	3.32	5.03	6.75	1.31	15 3/4	-------	-------	-------	14.09	18.92
.66	7 3/4	1.67	2.53	3.40	5.15	6.90	1.32	15 13/16	-------	-------	-------	14.24	19.12
.67	7 7/8	1.71	2.59	3.47	5.26	7.05	1.33	15 7/8	-------	-------	-------	14.40	19.34
.68	8 1/16	1.74	2.64	3.56	5.38	7.21	1.34	16 1/16	-------	-------	-------	14.56	19.55
.69	8 1/8	1.78	2.70	3.63	5.49	7.36	1.35	16 1/8	-------	-------	-------	14.72	19.77
.70	8 1/4	1.82	2.76	3.71	5.61	7.52	1.36	16 1/4	-------	-------	-------	14.88	19.98
.71	8 3/8	1.86	2.81	3.78	5.73	7.68	1.37	16 3/8	-------	-------	-------	15.04	20.20
.72	8 1/2	1.90	2.87	3.86	5.85	7.84	1.38	16 1/2	-------	-------	-------	15.20	20.42
.73	8 5/8	1.93	2.93	3.94	5.97	8.00	1.39	16 5/8	-------	-------	-------	15.36	20.64
.74	8 3/4	1.97	2.99	4.02	6.09	8.17	1.40	16 3/4	-------	-------	-------	15.53	20.86
.75	9	2.01	3.05	4.10	6.21	8.33	1.41	16 13/16	-------	-------	-------	15.69	21.08
.76	9 1/8	2.05	3.11	4.18	6.33	8.49	1.42	16 7/8	-------	-------	-------	15.85	21.29
.77	9 1/4	2.09	3.17	4.26	6.45	8.66	1.43	17 1/16	-------	-------	-------	16.02	21.52
.78	9 3/8	2.13	3.23	4.34	6.58	8.82	1.44	17 1/8	-------	-------	-------	16.19	21.74
.79	9 1/2	2.17	3.29	4.42	6.70	8.99	1.45	17 1/4	-------	-------	-------	16.34	21.96
.80	9 5/8	2.21	3.35	4.51	6.83	9.16	1.46	17 3/8	-------	-------	-------	16.51	22.18
.81	9 3/4	2.25	3.41	4.59	6.95	9.33	1.47	17 1/2	-------	-------	-------	16.68	22.41
.82	9 13/16	2.29	3.47	4.67	7.08	9.50	1.48	17 5/8	-------	-------	-------	16.85	22.64
.83	9 7/8	2.33	3.54	4.75	7.21	9.67	1.49	17 3/4	-------	-------	-------	17.01	22.85
.84	10 1/16	2.37	3.60	4.84	7.33	9.84	1.50	18	-------	-------	-------	17.17	23.08
.85	10 1/8	2.41	3.66	4.92	7.46	10.01							

TABLE 6.—*Discharge tables for Cipolletti weirs with complete contractions*

Computed from the formula $Q=3.247\ LH^{1.49}-\frac{0.566L^{1.5}}{1+2L^{1.5}}H^{1.5}+0.609\ H^{2.5}$

Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths					Head in feet	Head in inches	Discharge in cubic feet per second for crests of various lengths				
		1 foot	1.5 feet	2 feet	3 feet	4 feet			1 foot	1.5 feet	2 feet	3 feet	4 feet
0.20	2 3/8	0.30	0.45	0.60	0.90	1.20	0.86	10 3/8	2.87	4.14	5.43	8.01	10.60
.21	2 1/2	.32	.48	.64	.97	1.29	.87	10 7/16	2.93	4.22	5.52	8.15	10.79
.22	2 5/8	.35	.52	.69	1.04	1.38	.88	10 1/2	2.98	4.29	5.62	8.30	10.98
.23	2 3/4	.37	.55	.74	1.11	1.47	.89	10 9/16	3.04	4.37	5.72	8.44	11.17
.24	2 7/8	.39	.59	.79	1.18	1.57	.90	10 5/8	3.09	4.45	5.82	8.59	11.36
.25	3	.42	.63	.84	1.25	1.67	.91	10 11/16	3.15	4.53	5.92	8.73	11.55
.26	3 1/8	.45	.67	.89	1.33	1.77	.92	10 3/4	3.20	4.60	6.02	8.88	11.74
.27	3 1/4	.47	.70	.94	1.40	1.87	.93	10 13/16	3.26	4.68	6.13	9.03	11.94
.28	3 3/8	.50	.74	.99	1.48	1.97	.94	10 7/8	3.32	4.76	6.23	9.17	12.13
.29	3 1/2	.53	.79	1.04	1.56	2.08	.95	10 15/16	3.37	4.84	6.33	9.32	12.33
.30	3 5/8	.56	.83	1.10	1.64	2.19	.96	11	3.43	4.92	6.44	9.48	12.53
.31	3 3/4	.59	.87	1.15	1.73	2.30	.97	11 1/16	3.49	5.00	6.55	9.62	12.72
.32	3 13/16	.61	.91	1.21	1.80	2.41	.98	11 1/8	3.55	5.09	6.64	9.78	12.92
.33	3 15/16	.64	.95	1.27	1.89	2.52	.99	11 3/16	3.61	5.17	6.75	9.93	13.12
.34	4 1/16	.67	1.00	1.32	1.98	2.64	1.00	12	3.67	5.25	6.86	10.08	13.32
.35	4 1/8	.70	1.04	1.38	2.07	2.75	1.01	12 1/16	-------	5.33	6.96	10.24	13.53
.36	4 1/4	.73	1.09	1.44	2.16	2.87	1.02	12 1/8	-------	5.42	7.07	10.40	13.73
.37	4 3/8	.77	1.13	1.50	2.25	2.99	1.03	12 3/16	-------	5.50	7.18	10.55	13.94
.38	4 1/2	.80	1.18	1.57	2.34	3.11	1.04	12 1/4	-------	5.59	7.29	10.71	14.15
.39	4 5/8	.83	1.23	1.63	2.43	3.24	1.05	12 5/16	-------	5.67	7.40	10.87	14.35
.40	4 3/4	.87	1.28	1.69	2.53	3.36	1.06	12 3/8	-------	5.76	7.51	11.03	14.56
.41	4 7/8	.90	1.32	1.76	2.62	3.49	1.07	12 7/16	-------	5.84	7.62	11.18	14.76
.42	5	.93	1.37	1.82	2.72	3.61	1.08	12 1/2	-------	5.93	7.73	11.35	14.98
.43	5 1/16	.97	1.42	1.89	2.81	3.74	1.09	12 9/16	-------	6.02	7.84	11.51	15.19
.44	5 1/8	1.00	1.47	1.95	2.91	3.87	1.10	12 5/8	-------	6.11	7.96	11.68	15.41
.45	5 1/4	1.04	1.53	2.02	3.01	4.01	1.11	12 11/16	-------	6.20	8.07	11.84	15.62
.46	5 5/16	1.07	1.58	2.09	3.11	4.14	1.12	12 3/4	-------	6.29	8.18	12.00	15.84
.47	5 3/8	1.11	1.63	2.16	3.21	4.28	1.13	12 13/16	-------	6.37	8.29	12.16	16.04
.48	5 1/2	1.15	1.68	2.23	3.32	4.41	1.14	12 7/8	-------	6.46	8.41	12.33	16.26
.49	5 5/8	1.18	1.74	2.30	3.42	4.55	1.15	12 15/16	-------	6.56	8.53	12.50	16.48
.50	6	1.22	1.79	2.37	3.53	4.69	1.16	13	-------	6.65	8.65	12.67	16.70
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.17	13 1/16	-------	6.74	8.76	12.84	16.93
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.18	13 1/8	-------	6.83	8.88	13.01	17.15
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.19	13 3/16	-------	6.93	9.00	13.18	17.37
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.20	13 1/4	-------	7.02	9.12	13.35	17.59
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.21	13 5/16	-------	7.11	9.24	13.52	17.81
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.22	13 3/8	-------	7.20	9.36	13.69	18.03
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.23	13 7/16	-------	7.30	9.48	13.87	18.27
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.24	13 1/2	-------	7.40	9.60	14.04	18.49
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.25	15	-------	7.49	9.72	14.21	18.71
.60	7 1/8	1.62	2.37	3.13	4.64	6.17	1.26	15 1/16	-------	-------	-------	14.39	18.95
.61	7 1/4	1.67	2.43	3.20	4.76	6.32	1.27	15 1/8	-------	-------	-------	14.56	19.17
.62	7 5/16	1.71	2.49	3.28	4.88	6.47	1.28	15 3/16	-------	-------	-------	14.74	19.41
.63	7 3/8	1.75	2.55	3.37	5.00	6.63	1.29	15 1/4	-------	-------	-------	14.92	19.65
.64	7 1/2	1.80	2.62	3.45	5.12	6.79	1.30	15 5/16	-------	-------	-------	15.11	19.88
.65	7 5/8	1.84	2.68	3.53	5.24	6.95	1.31	15 3/8	-------	-------	-------	15.29	20.12
.66	7 3/4	1.89	2.75	3.61	5.36	7.11	1.32	15 7/16	-------	-------	-------	15.46	20.34
.67	7 15/16	1.93	2.81	3.70	5.48	7.28	1.33	15 1/2	-------	-------	-------	15.64	20.58
.68	8 1/16	1.98	2.87	3.79	5.61	7.44	1.34	16 1/16	-------	-------	-------	15.82	20.82
.69	8 1/8	2.02	2.94	3.87	5.73	7.61	1.35	16 1/8	-------	-------	-------	16.01	21.06
.70	8 1/4	2.07	3.01	3.95	5.86	7.77	1.36	16 3/16	-------	-------	-------	16.19	21.29
.71	8 5/16	2.12	3.07	4.04	5.99	7.94	1.37	16 1/4	-------	-------	-------	16.37	21.53
.72	8 3/8	2.16	3.14	4.13	6.12	8.11	1.38	16 5/16	-------	-------	-------	16.57	21.78
.73	8 1/2	2.21	3.21	4.22	6.24	8.28	1.39	16 3/8	-------	-------	-------	16.75	22.02
.74	8 5/8	2.26	3.28	4.31	6.38	8.45	1.40	16 7/16	-------	-------	-------	16.94	22.27
.75	9	2.31	3.35	4.40	6.51	8.62	1.41	16 1/2	-------	-------	-------	17.13	22.51
.76	9 1/8	2.36	3.42	4.49	6.64	8.80	1.42	17 1/16	-------	-------	-------	17.31	22.75
.77	9 1/4	2.41	3.49	4.58	6.77	8.97	1.43	17 1/8	-------	-------	-------	17.51	23.01
.78	9 3/8	2.46	3.56	4.67	6.90	9.15	1.44	17 3/16	-------	-------	-------	17.70	23.26
.79	9 1/2	2.51	3.63	4.76	7.04	9.33	1.45	17 1/4	-------	-------	-------	17.89	23.50
.80	9 5/8	2.56	3.70	4.85	7.18	9.51	1.46	17 5/16	-------	-------	-------	18.08	23.75
.81	9 3/4	2.61	3.77	4.95	7.31	9.69	1.47	17 3/8	-------	-------	-------	18.28	24.01
.82	9 13/16	2.66	3.84	5.04	7.45	9.87	1.48	17 7/16	-------	-------	-------	18.47	24.26
.83	9 15/16	2.71	3.92	5.14	7.59	10.05	1.49	17 1/2	-------	-------	-------	18.66	24.50
.84	10 1/16	2.77	3.99	5.23	7.73	10.23	1.50	18	-------	-------	-------	18.85	24.75
.85	10 1/8	2.82	4.07	5.33	7.87	10.42							

TABLE 7.—*Discharge table for 90° triangular notch with complete contractions*

Computed from the formula $Q=2.49\ H^{2.48}$

Head in feet	Head in inches	Discharge in second-feet (Q)	Head in feet	Head in inches	Discharge in second-feet (Q)	Head in feet	Head in inches	Discharge in second-feet (Q)
0.20	2 3/8	0.046	0.55	6 5/8	0.564	0.90	10 13/16	1.92
.21	2 1/2	.052	.56	6 3/4	.590	.91	10 15/16	1.97
.22	2 5/8	.058	.57	6 13/16	.617	.92	11 1/16	2.02
.23	2 3/4	.065	.58	6 15/16	.644	.93	11 1/8	2.08
.24	2 7/8	.072	.59	7 1/16	.672	.94	11 1/4	2.13
.25	3	.080	.60	7 1/8	.700	.95	11 3/8	2.19
.26	3 1/8	.088	.61	7 5/16	.730	.96	11 1/2	2.25
.27	3 1/4	.096	.62	7 7/16	.760	.97	11 5/8	2.31
.28	3 3/8	.106	.63	7 1/2	.790	.98	11 3/4	2.37
.29	3 1/2	.115	.64	7 11/16	.822	.99	11 7/8	2.43
.30	3 5/8	.125	.65	7 13/16	.854	1.00	12	2.49
.31	3 3/4	.136	.66	7 15/16	.887	1.01	12 1/8	2.55
.32	3 7/8	.147	.67	8 1/16	.921	1.02	12 1/4	2.61
.33	3 15/16	.159	.68	8 1/8	.955	1.03	12 3/8	2.68
.34	4 1/16	.171	.69	8 1/4	.991	1.04	12 1/2	2.74
.35	4 1/8	.184	.70	8 3/8	1.03	1.05	12 5/8	2.81
.36	4 5/16	.197	.71	8 1/2	1.06	1.06	12 3/4	2.87
.37	4 7/16	.211	.72	8 5/8	1.10	1.07	12 13/16	2.94
.38	4 1/2	.225	.73	8 3/4	1.14	1.08	12 15/16	3.01
.39	4 11/16	.240	.74	8 7/8	1.18	1.09	13 1/16	3.08
.40	4 13/16	.256	.75	9	1.22	1.10	13 1/8	3.15
.41	4 15/16	.272	.76	9 1/8	1.26	1.11	13 5/16	3.22
.42	5 1/16	.289	.77	9 1/4	1.30	1.12	13 7/16	3.30
.43	5 1/8	.306	.78	9 3/8	1.34	1.13	13 1/2	3.37
.44	5 5/16	.324	.79	9 1/2	1.39	1.14	13 5/8	3.44
.45	5 7/16	.343	.80	9 5/8	1.43	1.15	13 3/4	3.52
.46	5 1/2	.362	.81	9 3/4	1.48	1.16	13 7/8	3.59
.47	5 5/8	.382	.82	9 13/16	1.52	1.17	14 1/16	3.67
.48	5 3/4	.403	.83	9 15/16	1.57	1.18	14 1/8	3.75
.49	5 7/8	.424	.84	10 1/16	1.61	1.19	14 1/4	3.83
.50	6	.445	.85	10 1/8	1.66	1.20	14 3/8	3.91
.51	6 1/8	.468	.86	10 5/16	1.71	1.21	14 1/2	3.99
.52	6 1/4	.491	.87	10 7/16	1.76	1.22	14 5/8	4.07
.53	6 3/8	.515	.88	10 1/2	1.81	1.23	14 3/4	4.16
.54	6 1/2	.539	.89	10 11/16	1.86	1.24	14 7/8	4.24
						1.25	15	4.33

TABLE OF HYDRAULIC EQUIVALENTS

1 cubic foot equals 7.48 gallons, or approximately 7½ gallons.
1 cubic foot of water weighs approximately 62½ pounds.
1 cubic foot per second equals 448.83 gallons per minute, or approximately 450 gallons per minute.
1 cubic foot per second flowing for 1 hour equals approximately 1 acre-inch.
1 cubic foot per second flowing for 12 hours equals approximately 1 acre-foot.
1 cubic foot per second flowing for 24 hours equals approximately 2 acre-feet.
1 acre-foot equals 43,560 cubic feet, equals 325,851 gallons.
1,000,000 cubic feet equals 22.95 acre-feet.

In Arizona, Nevada, Montana, Oregon, and parts of California 1 miner's inch (statutory inch) equals $\frac{1}{40}$ of 1 cubic foot per second.

In southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska, and Utah 1 miner's inch (statutory inch) equals $\frac{1}{50}$ of 1 cubic foot per second.

In Colorado it is generally assumed that 1 cubic foot per second equals 38.4 miner's inches (statutory inches).